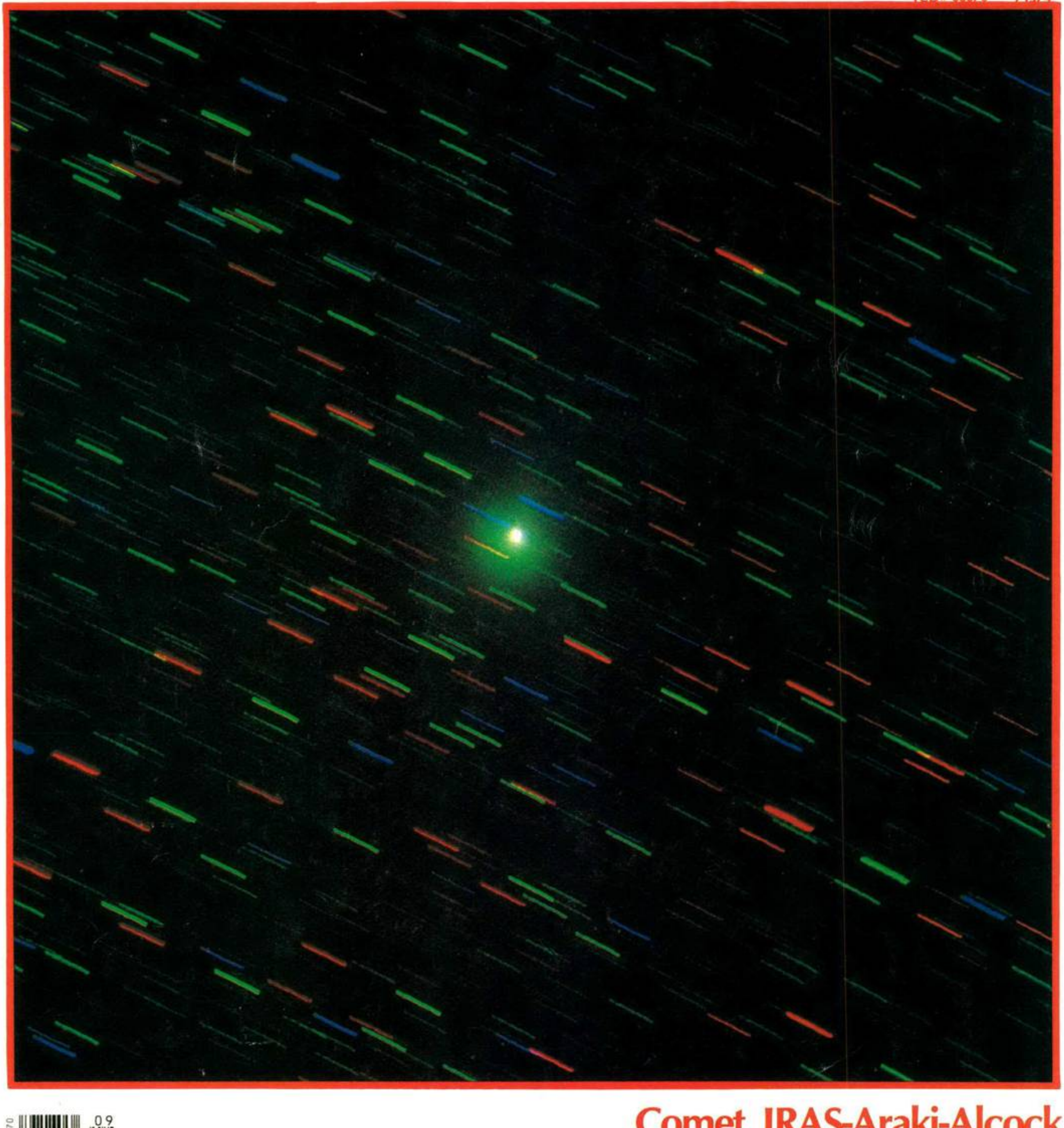
ASTRONOMY

September 1983
U.S. $2
UK £1.15
Can. $2.25

New Missions to the Planets
Four Probes to Comet Halley
The Indonesian Eclipse

ICD# 08070 71574



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Comet IRAS-Araki-Alcock

Meade® 4", 8", and 10" Schmidt-Cassegrains: So technically advanced they're warranted for life.

Meade Model 2080: 8" Schmidt-Cassegrain Telescope. (Shown with optional Rotary Eyepiece Holder.)

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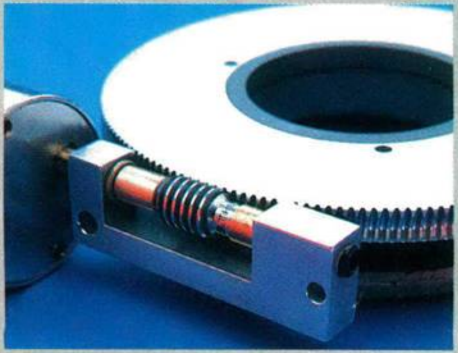

The standard worm-gear drive system of the Meade 8" Model 2080.

Meade diffraction-limited optics are polished to surface accuracies within 1/10-wavelength, and are manufactured and tested with the most precise optical test equipment available. Every 8" system, for example, is tested at 1000X on one of our laser autocollimators and corrected for extremely minute errors in the diffraction image – errors which are invisible to most observers at normal magnifications. Further, each 3-element optical set is **individually** hand-corrected to produce a knife-edge optical null and razor-straight bands under the Ronchi test. This battery of three independent optical tests assures that Meade Schmidt-Cassegrain optics are, without exception, the finest available in any commercial telescope.

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New LX (Long-Exposure) Drive System now Available on Meade 8" and 10" Schmidt-Cassegrains

For the most advanced astrophotographic applications, the new Meade LX Drive System is now available optionally at modest additional cost on the 8" Model 2080; the LX Drive System is now included as standard equipment at no additional charge on the Meade 10" Model 2120. The LX Drive includes custom gear components ground with extreme precision, and permits practical long-exposure photographs up to 2 hours' duration. ***The LX Drive System is warranted to equal or exceed the precision of any drive system available on any production Schmidt-Cassegrain telescope.***

Latitude scale of the Equatorial Wedge.

Advanced-Design Equatorial Wedge and Field Tripod Systems — The owner of a Meade Schmidt-Cassegrain will appreciate the attention to detail shown in the Meade Equatorial Wedge and Field Tripod. Each Wedge includes a latitude scale permitting accurate polar alignment of the telescope in a few **seconds,** not minutes. A universal bubble level, machined into the floor of the Wedge and also included as standard equipment, enables the observer to rapidly align the wedge/tripod system to the horizontal, without guesswork. Azimuth orientation is facilitated by the 360°-rotation capability of the Wedge on the Field Tripod — and by the fact that no wrenches or tools of any kind are required in the operation of 4" and 8" models, and only one hex wrench on 10" models.

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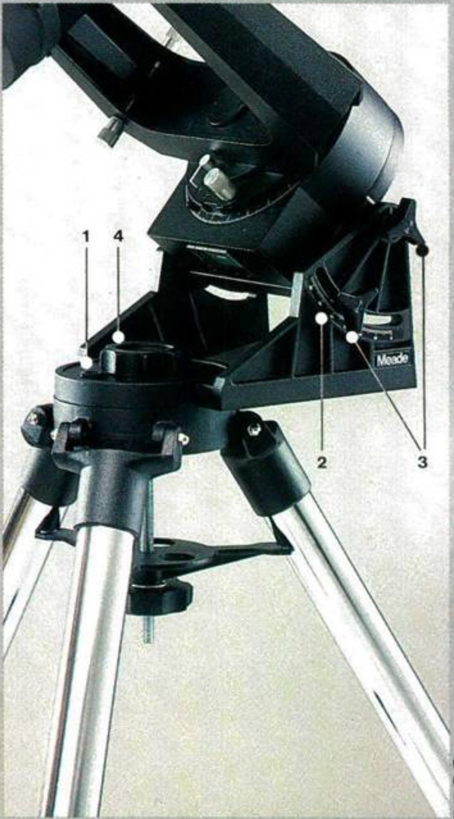

The Meade Equatorial Wedge/Field Tripod System.

(1) Bubble level; (2) Latitude scale; (3) No-Tool-Required adjustment knobs; (4) Wedge-to-Tripod lock knob, permitting 360° Wedge adjustments in azimuth.

for example, fits neatly in a cavity at the undersurface of one fork arm. Optional dew shields lock into a track pre-machined into the corrector cell of every 8" and 10" telescope. Other accessory systems, from sliding counterweights to the f/2.64 Schmidt Camera, attach directly to the standard telescopes without customer drilling or adaptation. The motivated observer will find an almost unlimited potential for growth, with an absolute minimum of observing time diverted to equipment maintenance and adjustment.

Great Nebula in Orion (M42). A 50-minute exposure on Ektachrome 400 through the Meade 8" Model 2080.

Lifetime Warranty — In the U.S.A. and Canada, Meade 4", 8", and 10" Schmidt-Cassegrain astronomical telescopes are **warranted for life** against defects in materials or manufacture. (Outside North America, see your Meade international distributor for details on his extended-term warranty.) The Meade General Catalog contains full details on this ultimate protection of your investment in astronomy.

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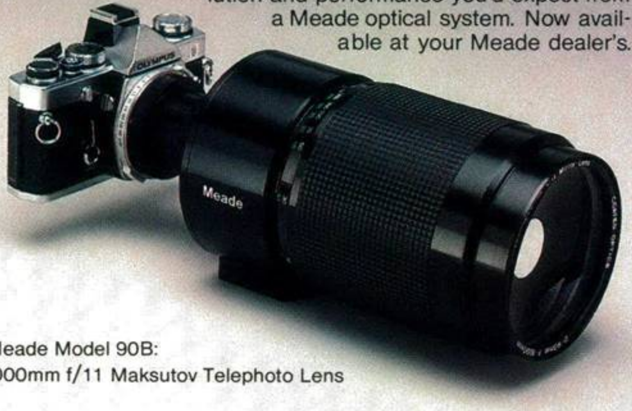
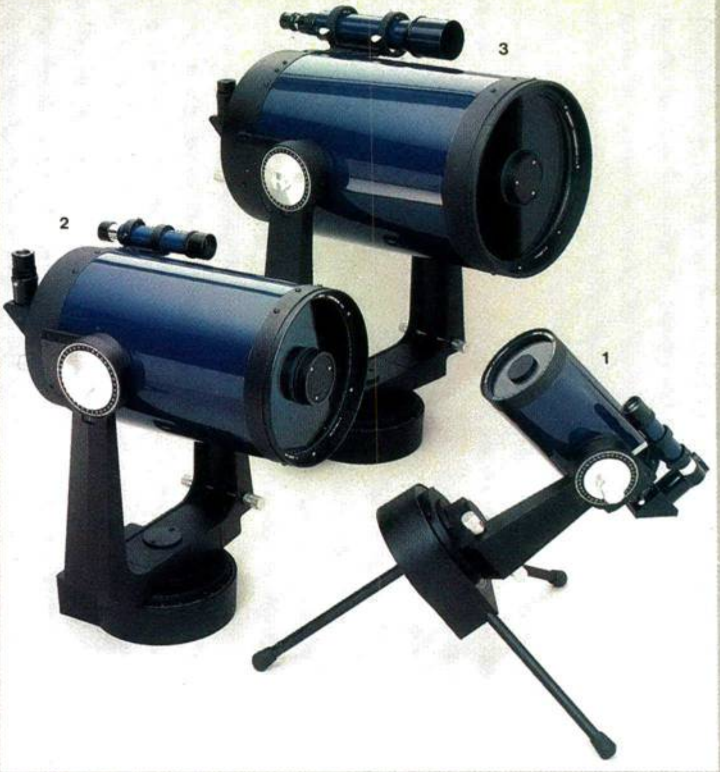


Meade Model 90B:
1000mm f/11 Maksutov Telephoto Lens



Meade Schmidt-Cassegrain Telescopes. (1) 4" Model 2044, with standard-equipment table tripod; (2) 8" Model 2080; (3) 10" Model 2120.

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Meade Instruments Corporation
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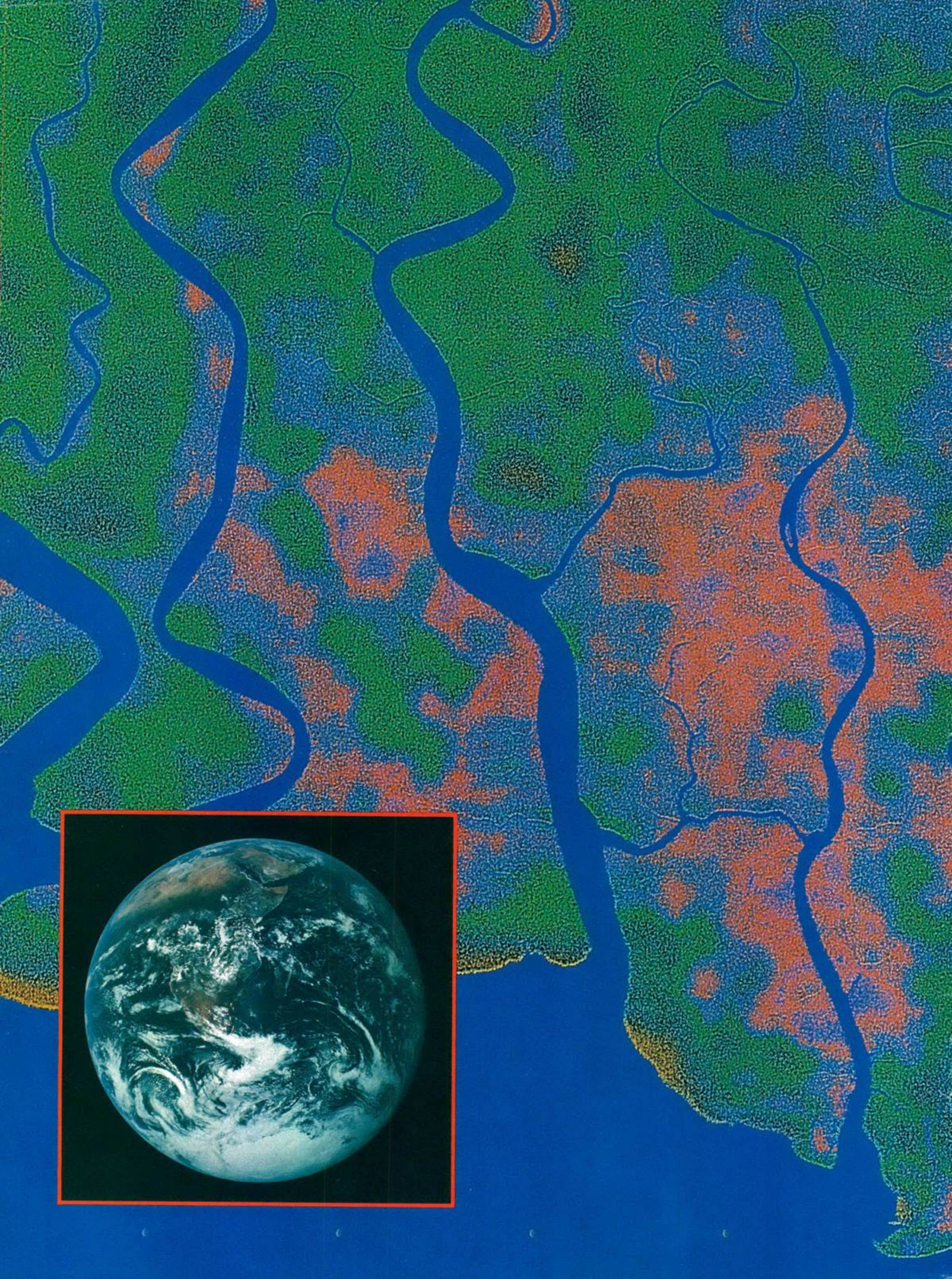

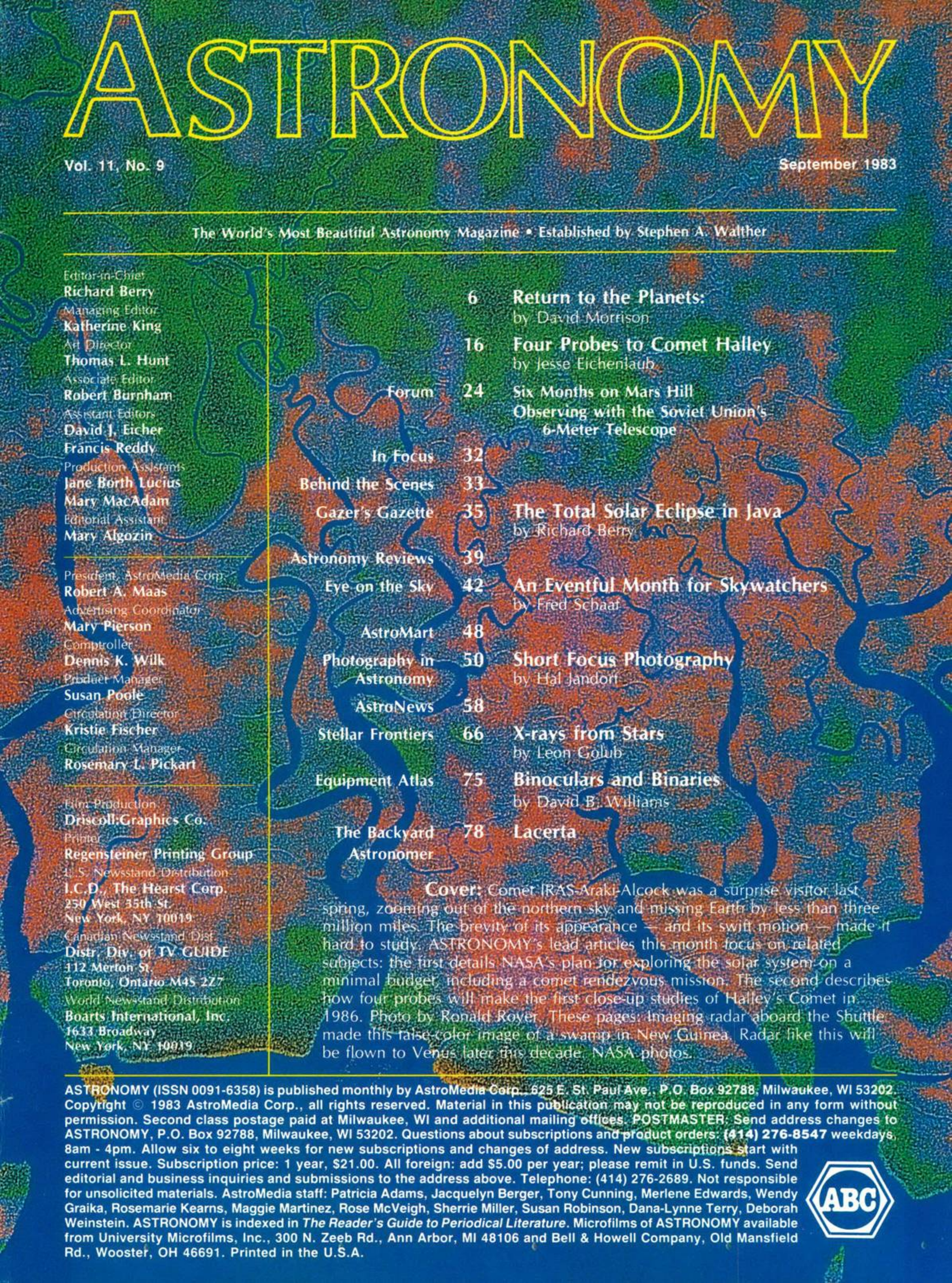

ASTRONOMY

Vol. 11, No. 9 September 1983

The World's Most Beautiful Astronomy Magazine • Established by Stephen A. Walther

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Cover: Comet IRAS-Araki-Alcock was a surprise visitor last spring, zooming out of the northern sky and missing Earth by less than three million miles. The brevity of its appearance — and its swift motion — made it hard to study. ASTRONOMY's lead articles this month focus on related subjects: the first details NASA's plan for exploring the solar system on a minimal budget, including a comet rendezvous mission. The second describes how four probes will make the first close-up studies of Halley's Comet in 1986. Photo by Ronald Royer. These pages: Imaging radar aboard the Shuttle made this false-color image of a swamp in New Guinea. Radar like this will be flown to Venus later this decade. NASA photos.

ASTRONOMY (ISSN 0091-6358) is published monthly by AstroMedia Corp., 625 E. St. Paul Ave., P.O. Box 92788, Milwaukee, WI 53202.

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Second class postage paid at Milwaukee, WI and additional mailing offices. POSTMASTER: Send address changes to ASTRONOMY, P.O. Box 92788, Milwaukee, WI 53202. Questions about subscriptions and product orders: **(414) 276-8547** weekdays, 8am - 4pm. Allow six to eight weeks for new subscriptions and changes of address. New subscriptions start with current issue. Subscription price: 1 year, $21.00. All foreign: add $5.00 per year; please remit in U.S. funds. Send editorial and business inquiries and submissions to the address above. Telephone: (414) 276-2689. Not responsible for unsolicited materials. AstroMedia staff: Patricia Adams, Jacquelyn Berger, Tony Cunning, Merlene Edwards, Wendy Graika, Rosemarie Kearns, Maggie Martinez, Rose McVeigh, Sherrie Miller, Susan Robinson, Dana-Lynne Terry, Deborah Weinstein. ASTRONOMY is indexed in *The Reader's Guide to Periodical Literature*. Microfilms of ASTRONOMY available from University Microfilms, Inc., 300 N. Zeeb Rd., Ann Arbor, MI 48106 and Bell & Howell Company, Old Mansfield Rd., Wooster, OH 46691. Printed in the U.S.A.

ABC

Return to the Planets:

A Blueprint for the Future

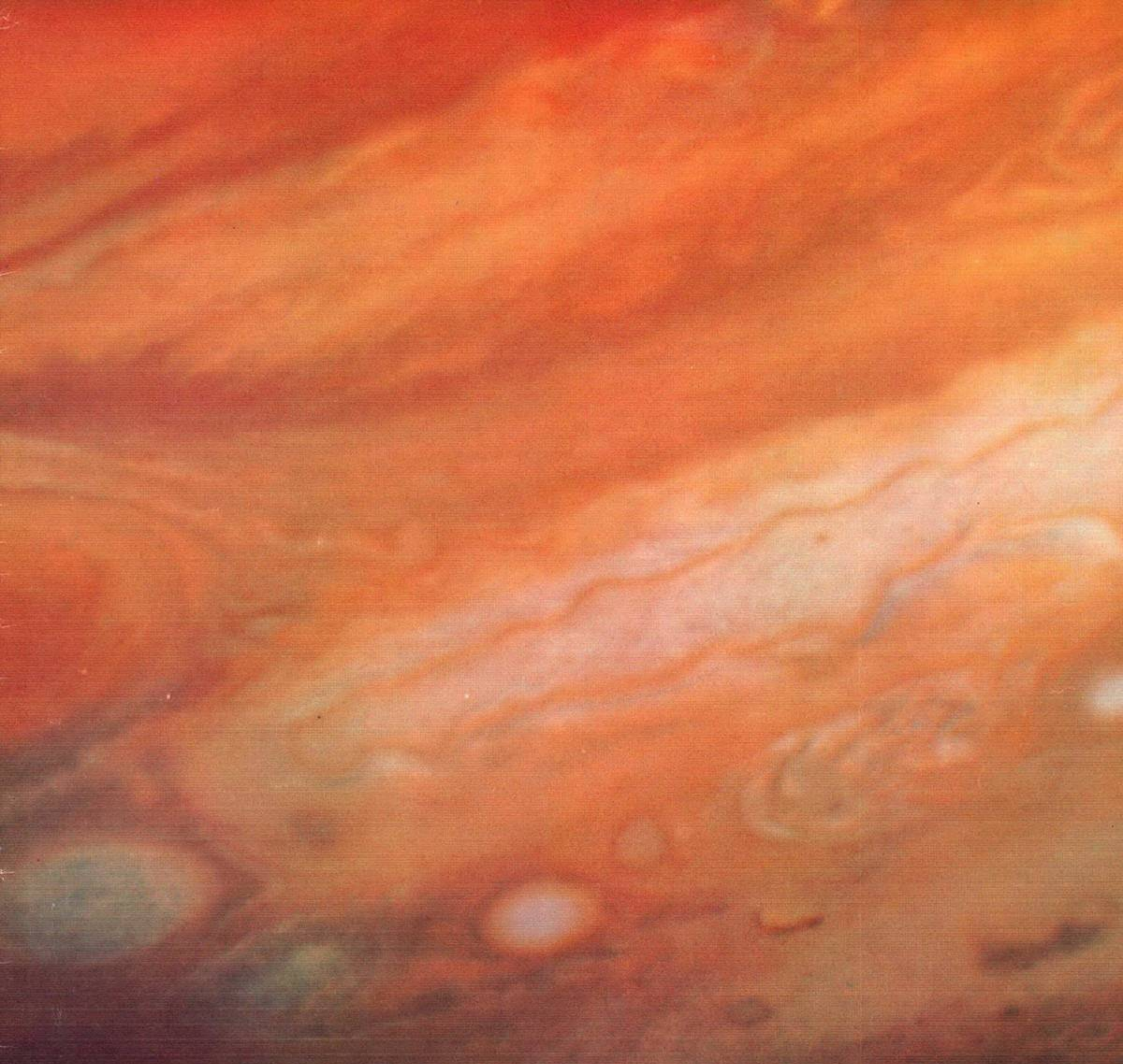
by David Morrison

A little more than two decades ago, on August 26, 1962, the first successful interplanetary spacecraft blasted off from Cape Canaveral on an Atlas-Agena rocket. One hundred and eight days later, after a harrowing voyage that often skirted disaster, Mariner 2 sailed past our sister planet Venus, transmitting to Earth the first close-up data from another world. Two years later a second Mariner, carrying a simple television camera, lifted off for Mars. More flights followed, as robots named Mariner, Pioneer, Viking, and Voyager fanned out through our planetary system. By August of 1978, when the last planetary flight began, 17 successful U.S. spacecraft had blazed the trails to other worlds, from Mercury to Saturn. During the same period, 12 U.S. astronauts walked on the Moon and several Soviet Venera spacecraft landed on the surface of Venus. Almost any observer would have concluded that the way lay open for the scientific exploration, and perhaps even the utilization, of the planets.

But as we all know, things have not worked out quite that way. Since 1978, not one U.S. planetary spacecraft has begun its celestial journey, while declining NASA budgets and costly delays in the Shuttle and its upper stage have threatened the very existence of a U.S. planetary exploration program. The single mission under development — the Galileo Jupiter orbiter and probe — required emergency resuscitation on an almost annual basis, while its target launch year slipped from 1982 to 1986. Even as the spectacular discoveries of Voyager were radioed back from Jupiter and Saturn, supporters of the space program realized that we were living on borrowed time. Unless the inexorable drop in planetary budgets were reversed and development of new missions initiated, there simply would not be a planetary program in the 1980s and 90s.

Quite suddenly, this situation appears to have improved. After three years of doom and gloom, NASA officials and planetary scientists once again speak with enthusiasm about new missions. The administration's Office of Science and Technology Policy, recently a severe critic of planetary exploration, now supports new initiatives. And NASA and the Air Force, after years of jockeying for position, are working together on the development of a powerful Centaur upper stage capable of launching planetary spacecraft from the Shuttle. Could a new golden age of planetary exploration lie just around the corner?

Much of the renewed enthusiasm for exploring the planets centers around the recently completed report of NASA's Solar System Exploration Committee (SSEC), an official agency advisory committee formed in 1980 to take a fresh look at planetary missions during the rest of this century. Predictably, the leading scientists on the committee gave a strong endorsement to continued exploration. But more important in the current fiscal climate, they pointed out ways to carry on this exploration at bargain prices. If their calculations are correct, 12 to 15 missions — about the total number of planetary flights to date — can be launched by the year 2000, but at a price approximately half of the average spent during the past

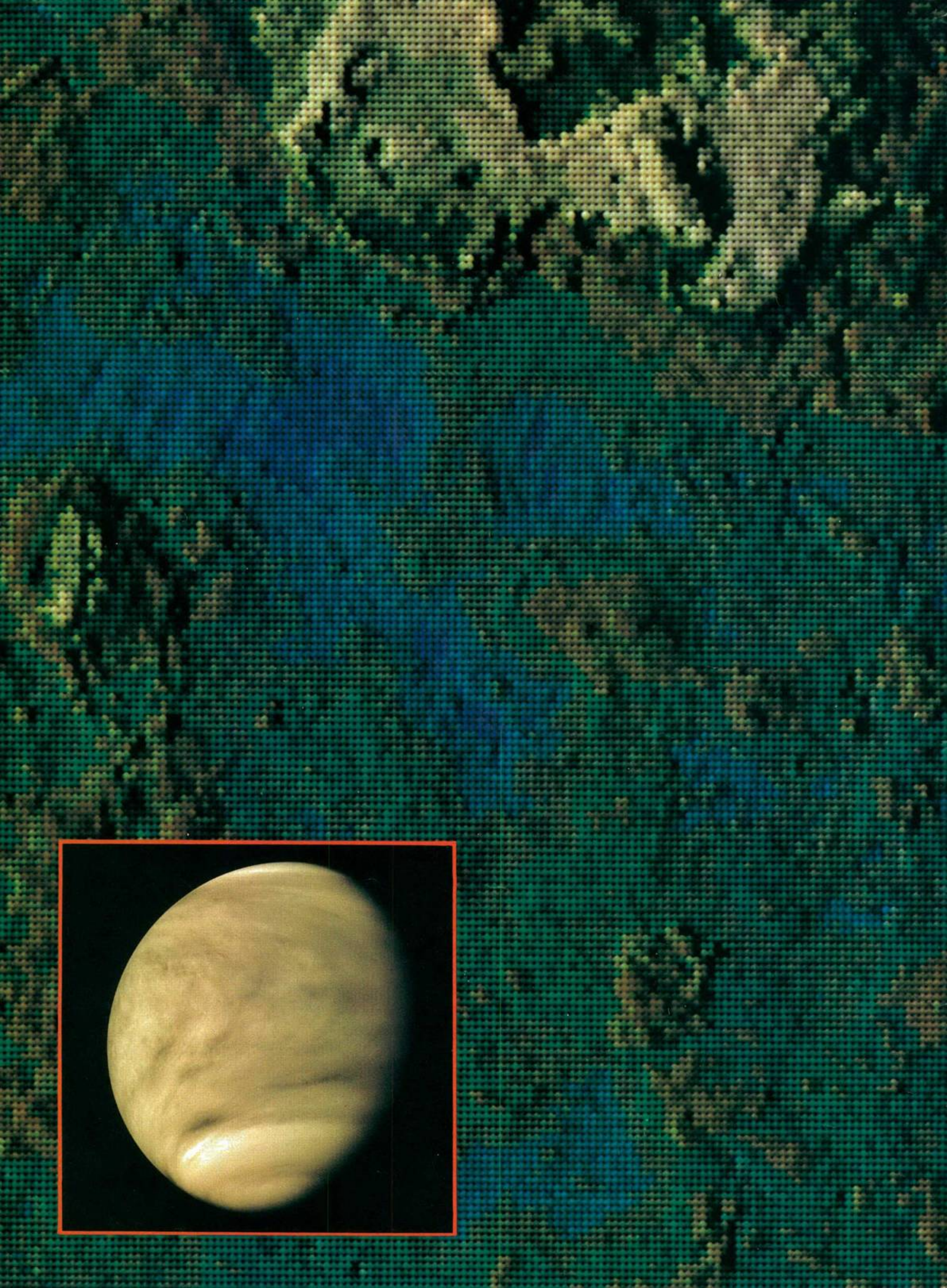


Jupiter photos from JPL/NASA

20 years. In current value dollars, that amounts to less than $350 million a year — just 5% of the NASA budget (which altogether amounts to only one cent of each federal dollar spent).

How are these savings possible? The Solar System Exploration Committee suggests several approaches. First, it recommends deferring really large missions that require new technologies. Exciting as it would be to operate a rover vehicle on Mars or to bring back a sample of cometary ice and dust for analysis on Earth, such ambitious missions are hardly in the "bargain" class. The most cost-effective spacecraft are the ones that we already know how to build — the planetary flybys, orbiters, and atmospheric entry probes that have been the mainstay of our program up to now. These techniques can be applied relatively cheaply.

We can also save money by grouping missions together, rather than treating each as a unique event. When building an orbiter to investigate the chemistry of the martian surface, why not construct a second, nearly identical, craft for a similar mapping mission to the Moon? Or, when purchasing a probe for the atmosphere of



Jupiter, why not buy additional probes for Saturn, Uranus, and Neptune while the manufacturer is tooled up and the price is right? Such economies seem obvious, but they have been precluded in the past by funding practices that treated each mission as if it were to be the last ever flown.

The inefficiencies in one-of-a-kind, custom-designed spacecraft can also be avoided by purchasing "off the shelf" spacecraft from the aerospace industry. Several types of commercial Earth-orbiting satellites, launched in substantial numbers for communication and surveillance, can be adapted for missions to Venus, Mars, the Moon, and some Earth-approaching asteroids. However, satellites developed for Earth orbit cannot handle the feeble sunlight, deep cold, and demanding communications requirements of the outer solar system — beyond the orbit of Mars, say. Forays to the giant planets, comets, and asteroids demand specialized craft like the Voyagers and Galileo. A new generation of such spacecraft, using a simple modular design, is under study at the Jet Propulsion Laboratory. Called the Mariner Mark II, it will provide the means to accomplish the new type of mission to the outer solar system.

All of the Mariner Mark II spacecraft, like Galileo, will be launched by the Shuttle with a Centaur upper stage. The development of Centaur for the Shuttle is an important element in the planetary exploration strategy. Missions to the planets — especially to the outer ones — as well as comets and asteroids, have special requirements not satisfied by most rockets. The Shuttle, in particular, was not designed with such deep space missions in mind. It is an economical vehicle designed to place large payloads into low Earth orbit. This is fine for many satellites, including the Space Telescope to be launched in 1986. But for many other applications an additional rocket stage is required.

To reach geosynchronous Earth orbit from the Shuttle, a payload must be boosted to a 24-hour orbit at an altitude of nearly 40,000 kilometers. To accomplish this, NASA and the Air Force have built a new two-stage solid-fuel rocket called the IUS, or inertial upper stage. Unfortunately, the IUS failed during its first flight in April 1983, when it should have boosted NASA's tracking and data relay satellite (TDRS-A) up to geosynchronous orbit from the Shuttle Challenger. But even when it works perfectly, the IUS will still not be powerful enough to launch large payloads to the planets.

The answer for most planetary applications is Centaur, a liquid-hydrogen, liquid-oxygen rocket that weighs about 20 tons. The Centaur has been a workhorse of the space program for 20 years, and has launched, among many other payloads, the Viking Mars spacecraft and the Voyagers to Jupiter and Saturn. The decision to modify Centaur for use with the Shuttle was a long political struggle, not resolved until a year ago. But its development is now underway, with the first Shuttle/Centaur flights scheduled for 1986.

With Shuttle/Centaur, a number of planetary missions are possible that can never be achieved with the solid-fuel IUS. In fact, the expected performance of the Centaur is so good that the SSEC has specifically recommended against developing any other planetary propulsion system, such as solar sails or solar electric ion drives, for the near future. This will insure against delays that might crop up in the development of new propulsion technologies.

Insisting on a cost-conscious approach to planetary exploration appears to be a political requirement for programs in the current economic climate. But the real strength of the newly proposed program is its scientific and exploration potential. Past missions revealed only a glimpse of the wonders of the solar system, but they provide a solid foundation upon which we can base a new generation of missions.

The highest priority mission in the SSEC program is a Venus Radar Mapper (VRM), which will give us our first look at the geology of Earth's sister planet. Venus has nearly the same size, mass, and chemical composition as Earth and comes closer to us than any other planet. In spite of these similarities, however, the atmosphere of Venus could hardly be more different from our own. Composed primarily of carbon dioxide, its pressure is 90 times greater than that of Earth, and its sulfuric acid clouds shroud a surface hot enough to melt lead. Because the clouds are opaque, we know very little about the surface and, hence, about the geological evolution of Venus. Has its crust experienced the large-scale plate tectonics that create and maintain the Earth's continents, mountain ranges, and active volcanos? Did it once have oceans, whose basins and wave-cut margins might still be visible? Does Venus, as some scientists have speculated, experience volcanic eruptions today? These are the kinds of questions that the Venus Radar Mapper will address.

We learned about the geology of the Moon from the Lunar Orbiter series of spacecraft and about Mars from the Mariner 9 orbiter. But optical cameras, such as those carried to the Moon and Mars, cannot penetrate the opaque cloud blanket of Venus. To achieve a geological reconnaissance similar in resolution we must turn to the techniques of imaging radar, recently demonstrated from Earth orbit by SEASAT and the third Shuttle flight. VRM will place an imaging radar in orbit around Venus; over a period of about eight months, it will map nearly the entire surface at a resolution of one kilometer or better. These maps promise to create a whole new science of venusian geology and to provide the basis for a detailed comparison of the histories of the three most Earth-like planets: Mars, Venus, and Earth itself.

VRM is not just a proposed mission — initial funding of $29 million for Fiscal Year 1984 was in this year's NASA budget, and so far Congress has enthusiastically supported it. NASA has selected the scientific instruments, completed the radar design, and is making preparations to proceed with implementation on October 1. If approved — the first planetary "new start" since Galileo in 1977 — VRM will be launched by the Shuttle/Centaur in 1988 and can be returning radar maps before the end of that year.

The next three missions in the proposed plan could all be launched by the end of the present decade. They are not included in the Fiscal Year 1984 budget now under consideration by Congress, but will require support in NASA's FY '85 budget, now under development by the agency in concert with the Office of Management and Budget. Also particularly important for FY '85 is a start on adapting commercial Earth satellites for planetary use, a program NASA calls the Planetary Observers.

The first Planetary Observer will probably be sent to

We've had a tantalizing glimpse of the landscape beneath the clouds of Venus, but we need a much more detailed view to piece together its geological history. The Venus Radar Mapper mission will provide a resolution about 100 times better than this, allowing a first look at venusian geologic processes. NASA photos.

Mars. The Viking Mars missions in the mid-1970s consisted of two landers, with life-detection and other direct experiments, supported by a detailed and extremely successful global mapping program carried out from orbit. The Viking landers taught us a great deal about the surface chemistry of two locations on Mars, but they also raised many questions about the chemical history of the surface as a whole. Particularly puzzling are the roles of water and carbon dioxide, which may migrate through the polar caps, atmosphere, surface soils, and subsurface permafrost in complex seasonal and climatic cycles. Some of the most intriguing post-Viking questions about the Red Planet concern its global chemistry and the history of its climate. Most scientists agree that the next step is an orbital survey, using what the SSEC calls a Mars Geoscience/Climatology Orbiter.

This Observer-class satellite would map Mars in much the same way as LANDSATs collect data on terrestrial geology and ecology. It would have a low polar orbit, providing a pole-to-pole scan in less than an hour. The minimum lifetime to cover one martian seasonal cycle is about two Earth years. Launch opportunities exist in 1988 and 1990, and current NASA projections call for a 1990 flight.

A satellite equipped to survey the chemistry of the martian surface would also be nearly ideal for a similar survey of our Moon. Because of its single-minded focus on the Apollo landings, the U.S. lunar program of the 1960s devoted almost all its effort to studying the equatorial regions that contained potential landing sites. In the early 1970s, just as lunar scientists were beginning plans for a broader scientific exploration of our satellite, all lunar missions were abruptly terminated. Ever since, lunar geologists have argued for a global survey, carried out by a relatively simple polar orbiter. Within the newly proposed Planetary Observer program, such an orbiter could be an inexpensive adjunct to the first Mars mission. And carrying this argument even further, we could readily send other Observer spacecraft for our first look at the small Earth-approaching asteroids.

After the spectacular discoveries of Voyager, it is inevitable that we should wish to return to the outer solar system, which contains 99% of the planetary mass, all but three of the 40 known moons, and at least three ring systems. Galileo will provide a comprehensive two-year study of Jupiter, its moons, and its magnetosphere. To be launched by Shuttle/Centaur in 1986, Galileo is scheduled to arrive at Jupiter in 1988 (at nearly the same time VRM orbits Venus) and to operate until 1990. Beyond Galileo, the most appealing objectives are in the Saturn system.

Saturn tempts us with many wonders, including its complex and beautiful rings and its varied moons. But surely the most fascinating object is the giant moon Titan, with a nitrogen-rich atmosphere deeper and more massive than that of Earth. The atmosphere of Titan is a chemist's delight, harboring complex reactions that may mimic those which formed organic compounds on the primitive Earth and thereby paved the way for the origin of life on our planet. The highest priority SSEC mission to the outer solar system is a Titan probe, which would drop instruments into the atmosphere and measure its properties down to the surface. In addition, the probe-carrier spacecraft could be instrumented with an imaging radar to provide a first snapshot of about 20 percent of the surface as it flies past — a kind of mini-VRM. A Titan Probe-Radar Mapper could be launched any year starting in the late 1980s; it will take nearly four years to reach its target.

Of nearly as much interest as the Titan Probe is a Galileo-class orbiter to study Saturn, its rings, and its other moons. Indeed, there has been substantial discussion of building a second Galileo spacecraft for this purpose. No decision has been made yet, but spare parts are being stockpiled to hold the option open. Talks are underway between the U.S. National Academy of Sciences and the European Science Foundation to consider a possible joint mission, with one side supplying the Saturn Orbiter and the other building the Titan Probe. There is enthusiasm for this plan on both sides of the Atlantic, but there are potential problems as well — including the 5 to 8-year trip time for an orbiter mission to Saturn. (An orbiter takes longer to arrive because its trajectory has more constraints.) That's a long time to wait for the fruits of a first U.S./European collaboration!

During the past 20 years, our robot spacecraft have explored much of the inner solar system and have begun the reconnaissance of the giant planets. But still untouched is the third major group of planetary targets: the comets and asteroids. Although much smaller than the planets, these numerous bodies have a special significance as remnants of the building blocks from which the solar system formed. Precisely because of their small size, they have remained relatively unchanged over the past 4.5 billion years. As a consequence of the exploration of the planets by spacecraft, astronomers have come to realize that every planet and major moon in the solar system has an extensive geological history. This evolution has largely destroyed the record of the first few hundred million years of solar system history. To understand the birth of our system, we must turn to the smaller, chemically more primitive bodies.

The first steps in the exploration of the comets will be taken in 1986, when Comet Halley makes its next once-in-a-lifetime visit to the Earth's neighborhood. Four spacecraft are planned to intercept Halley, but none will originate in the U.S. Instead, there will be Vega 1 and Vega 2, launched by the USSR with collaboration from several European nations, Planet A, the first Japanese planetary space mission, and Giotto, to be launched by the European Space Agency. (See "Four Probes to Comet Halley," page 16 this issue.) Several U.S. Halley missions were proposed, but all fell victim to budget cuts. The only American craft to study Halley will be ISEE-3, an Earth satellite designed to study the solar wind, which will be repositioned to observe the comet from a distance of slightly over 30 million kilometers.

Because Halley orbits the Sun in a direction opposite to that of the planets, it is a difficult target; the best that can be achieved is a fast flyby. At a relative speed of more than 50 kilometers per second, the spacecraft will pass through the head of the comet in a few hours and will have less than a minute for close-up viewing of the nucleus! This naturally limits the potential for spacecraft studies, even though Halley's size and brightness exceed any other accessible cometary target. The next step in cometary missions will be to select an easier target and

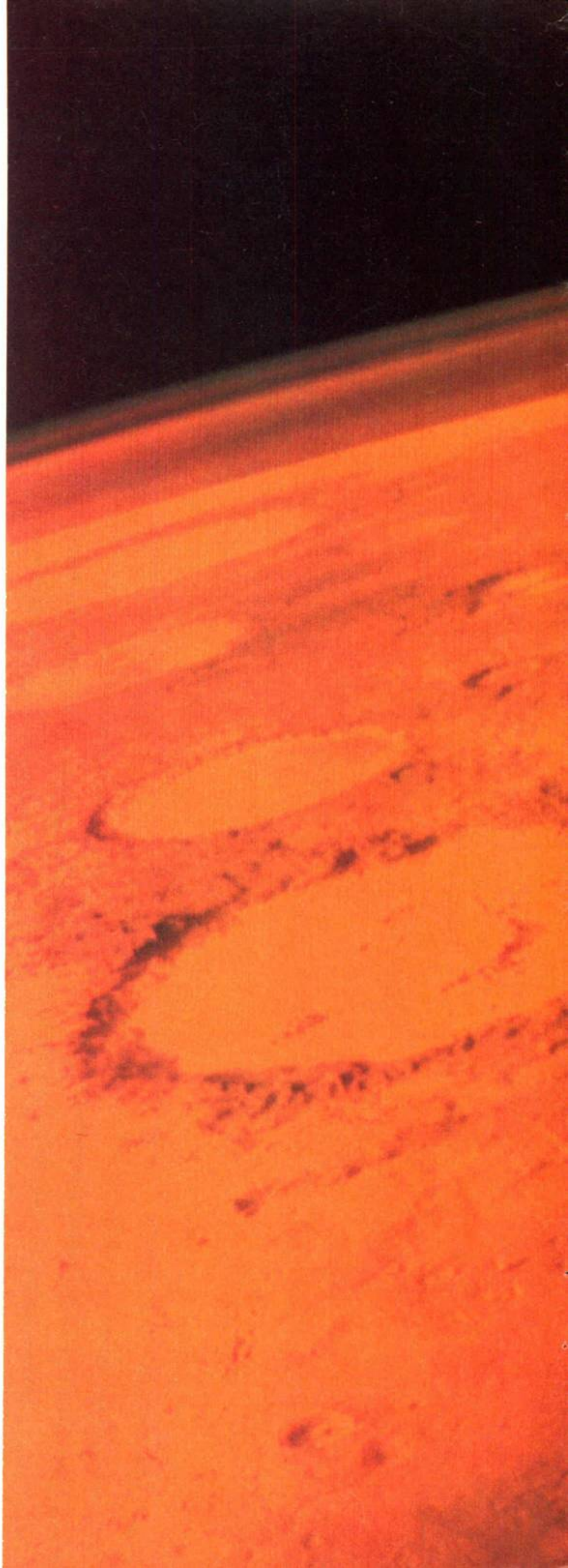
Although lunar exploration ended over a decade ago, many scientists hope NASA's new, low-budget missions will enable them to assess the Moon's properties on a broader scale than the Apollo-oriented studies of the 1960s and early 1970s. Apollo 16 photo from Lunar and Planetary Institute; inset, Fred Espenak.

rendezvous with it, placing the spacecraft in a parallel orbit and extending the observing time from minutes to months. The SSEC places high priority on such a comet rendezvous mission.

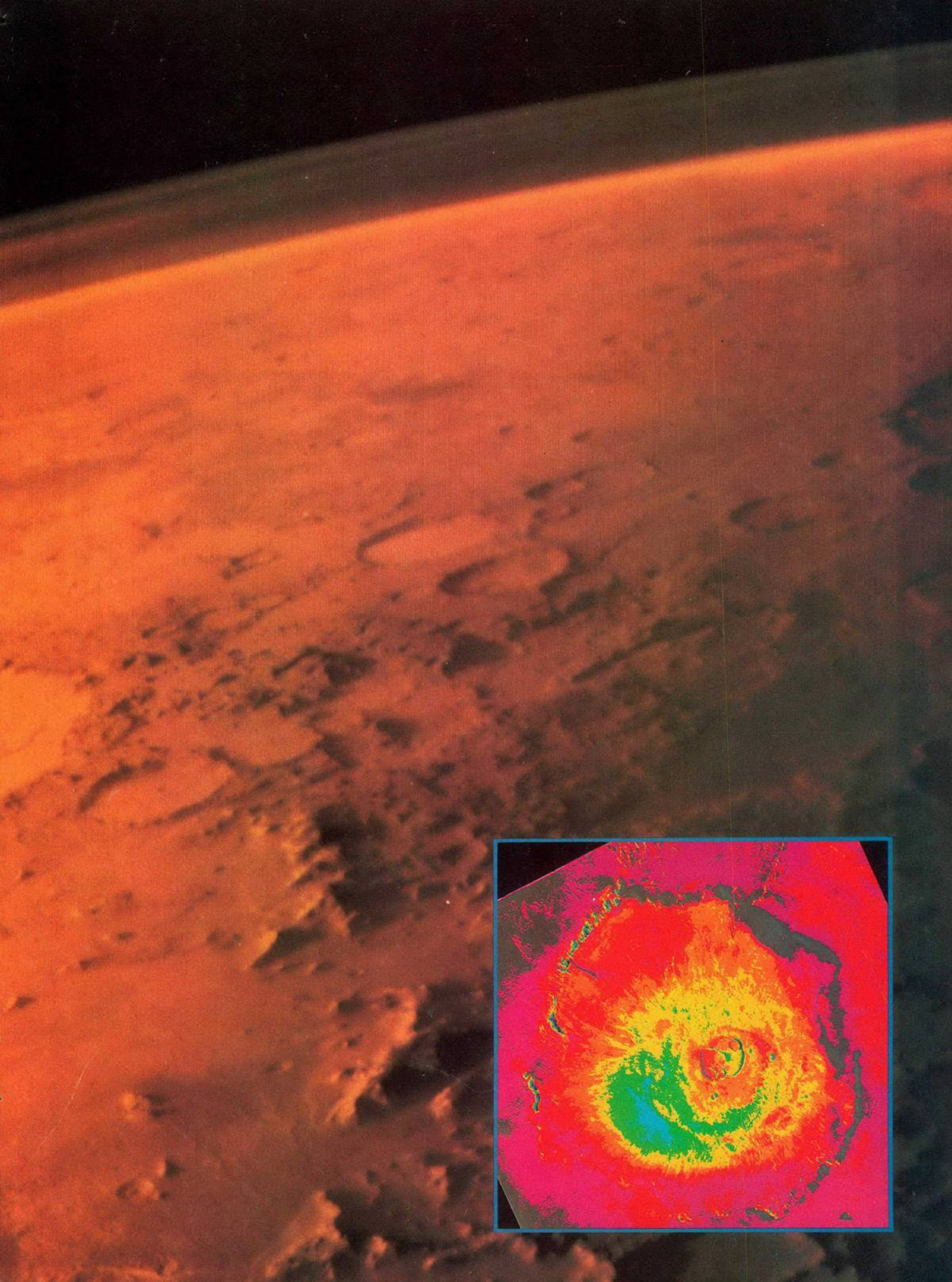
Engineering considerations dictate that the target be a short-period comet in an orbit little inclined to that of Earth, such as Comets Encke, Tempel 2, Wild 2, Honda-Mrkos-Pajdusakova, or Swift-Tuttle. Although much less spectacular than Halley, each of these objects displays the same range of fascinating activity as it nears the Sun. Ice in the solid nucleus, only one or two kilometers in diameter, is heated by sunlight to release an extensive atmosphere and ultimately to form a tail millions of kilometers in length. As the nucleus outgasses, it releases dust and solid materials, and interactions with the Sun's ultraviolet radiation and the solar wind create a cometary ionosphere. In many cases, the sources of activity are in the nucleus itself, suggesting that the subliming ice is released through volcanoes or geysers, while most of the surface may remain blanketed in dark dust or tar-like organic chemicals preserved since the birth of the planetary system. A rendezvous spacecraft that flies "in formation" with the comet can watch all these events as they take place, maneuvering around the nucleus to sample the ejected gas and dust, or retreating to a safe distance if the activity becomes too great. It is hard to imagine a more exciting exploratory mission.

The asteroids also are awaiting their first visits by spacecraft. Just as the icy comets probably represent the left-over planetary building blocks from the outer solar system, the asteroids appear to be remnants of the planetesimals that formed the rocky inner planets. Billions of years ago, most of these planetesimals were either swept up by the accreting planets or gravitationally ejected from the solar system. But a few survive in stable orbits between Mars and Jupiter, and occasionally small fragments even wander into the inner solar system, as Earth-approaching asteroids or meteoroids. The SSEC recommends an early mission to visit several asteroids, and at present a similar "asteroid tour," called Agora, is under study in Europe as a follow-on to the Giotto Halley mission. If the U.S. does not soon initiate comet and asteroid exploration, our European colleagues may claim this aspect of planetary science for themselves.

The first four missions in the SSEC recommendations are the Venus Radar Mapper, the Mars Orbiter, the Comet Rendezvous, and the Titan Probe. If accepted, these four missions (together with Galileo) would clearly put the U.S. back in the planetary exploration business. In this scenario, the current hiatus would end in 1988 with the arrivals of VRM at Venus and of Galileo at Jupiter. But the four initial missions are by no means the entire SSEC core program. According to the committee report, a total of 15 planetary missions can and should be launched by the year 2000. In fact, it is only by sustaining this kind of launch rate that we can realize many of the cost-saving efficiencies, such as a large amount of technological inheritance and shared mission operations. Ironically, a slowed-down program with fewer launches might cost just as much for a smaller return, due to reduced efficiency.



Where has the martian water gone? What is the planet's surface composition? The Mars Geoscience/Climatology Orbiter will survey the Red Planet for two years as it attempts to solve these two important questions. Inset: Olympus Mons in a photo processed to reveal lava flows of different ages. NASA photos.



Saturn's moon Titan is as much of a mystery now as Venus was 20 years ago. Since photochemical smogs completely hide the moon's surface, scientists plan to use a parachute probe to explore one location and a radar mapper to look through the shrouding haze. JPL/NASA photos.

Washington's reaction to the SSEC recommendations for a core program of planetary missions suggests that this plan, with its emphasis on low-cost missions, has struck a resonant chord with many decisionmakers in the administration and Congress. The President's Office of Science and Technology Policy praised the planetary science community for "getting its act together," and a congressional resolution endorsed the report. In addition, the prestigious National Academy of Sciences approved the scientific content of the recommendations. And most important, in a city where money speaks louder than words, congressional approval to the amount of $29 million in the FY '84 budget (to begin the Venus Radar Mapper) seems assured.

Although this new planetary mission plan was originally conceived as a U.S. program, there is substantial interest in making planetary exploration an international enterprise. Even these modest missions are not exactly cheap, and since budgets are constrained everywhere, there is an obvious incentive to join forces. Three activities during the past few months suggest ways in which such cooperation might come about.

At the Economic Summit meeting in Williamsburg last May, the leaders of the U.S., Canada, Japan, and the major western European nations endorsed solar system exploration as a means of stimulating the economies of the industrial states. Space missions both use and stimulate the high-technology industries that are increasingly important to our economy. This high-level endorsement of joint missions has not yet led to a specific plan of action, but it certainly encourages a search for cooperative efforts.

Also during the past year, a mission study has been underway by the U.S. National Academy of Sciences and the European Science Foundation. Three areas for possible planetary missions are being investigated: Mars, the Saturn system, and comets and asteroids. A report and recommendation from this group are expected in the fall.

The most specific idea under consideration for a joint planetary mission focuses on Saturn and Titan. Almost a year ago a number of European scientists proposed the mission they called Cassini (after the discoverer of several saturnian satellites and the main gap in the rings), which consists of two elements: a Saturn orbiter and a probe into the atmosphere of Titan. (Both craft are also on the SSEC list, but as separate missions.) At almost the same time, JPL engineers suggested to NASA that they could economically construct a duplicate Galileo spacecraft and entry probe suitable for a Saturn mission. Clearly, a combination of the Cassini and Galileo/Saturn ideas could generate a very attractive international mission. The version now favored calls for a U.S. Galileo orbiter and a European Titan probe. The difficulties in organizing any such multinational undertaking are formidable, but many people still hope this joint Saturn/Titan mission can become a reality.

So far we have discussed only relatively modest planetary missions. The SSEC recognized that the highest priority for the present was to regain momentum in planetary exploration through a number of relatively inexpensive initiatives. But it is also evident that the SSEC core program will leave much of the promise of the planets unfulfilled. Technologically, it hardly advances us beyond the kind of spacecraft we had a decade ago when Viking and Voyager were built. Obviously, the U.S. could go far beyond these minimum missions if the political will were present.

During the current year, the SSEC is examining a few of the larger, more technologically demanding missions that could augment the core program. Several exciting candidates have been suggested, one of them being the exploration of the surface of Mars with a rover or mobile laboratory. Ever since Viking, we have had the urge to "see over the next hill." Developing a truly autonomous craft — required by the long radio travel time between Earth and Mars (up to nearly an hour for a round trip signal) — is a major challenge. Solving these problems would contribute greatly to robotics and artificial intelligence research, as well as leading to tremendously exciting discoveries on Mars.

Another ambitious mission would collect martian rocks and soil and return them for analysis in terrestrial laboratories. Our studies of the Apollo lunar samples and meteorites demonstrate the profound insights into planetary history that modern analysis techniques can wrest from samples in the lab. But the U.S. has never developed automated sample-return technology (although the Russians have successfully returned Moon rocks using craft in their Luna series). One way to support a Mars sample return would be automated, on-site manufacture of rocket fuel from the martian atmosphere and soil using sunlight as an energy source. Although such an approach could save substantial weight on the lander spacecraft, it is unquestionably a challenging engineering task.

A somewhat similar mission could acquire a pristine sample of cometary ice and dust. The nucleus of a comet is probably the most chemically primitive material in the solar system, and is most likely to reveal the circumstances in which the Sun and planets were formed. But before we can plan a sample return in detail, we need the data from a precursor comet rendezvous mission. Another attractive large mission would involve a "buoyant station" floating like a hot-air balloon in the atmosphere of Titan. But here, also, we first need data from a Titan probe.

There's no shortage of good ideas for planetary missions and no question that the U.S. can develop the technology required to carry them out. By the 21st century, humans could be living in permanent habitations in Earth orbit and on the Moon, while our robot spacecraft explore the solar system, even bringing back small asteroids for industrial processing in space. That is the promise of the future. Yet for the present, our planetary program has virtually ground to a halt. The "data gap" of the 1980s is the product of past failures and cannot be corrected. What we *can* do is begin now to develop the new missions of the 1990s, those that will provide a transition into the expansive vision of the 21st century. The planetary missions of the SSEC core program, supplemented during the 1990s by the larger missions now under study, are designed to provide the transition. If we adopt this program, the new era of exploration that will begin later this decade should rival the 1970s in planetary discovery and exploration.

David Morrison is a planetary scientist at the Institute for Astronomy at the University of Hawaii. A member of the Voyager team, he is currently chairman of NASA's Solar System Exploration Committee.

4 probes to Comet Halley

By Jesse Eichenlaub

Comets have long fascinated and terrified the human race. The ancients believed these unpredictable visitors were omens of imminent wars, famines, and pestilence. During the middle ages, comets were thought to be fireballs cast down by God as warnings to sinners. Only in the last few centuries have we established their true nature, so that scientists regard them not as portents of the future, but "Rosetta Stones" of the solar system's remote past. In the 1980s, the peoples of Earth will, for the first time, send out robot emissaries to greet one of these visitors as it swings by the Sun — Comet Halley.

A comet is best described as a dirty snowball up to several kilometers in diameter, composed of ice, varying quantities of frozen gases, and dust. Most of the comets we can see from Earth travel in elliptical orbits that take them beyond the cold outer worlds of the solar system at *aphelion* (the point in an orbit farthest from the Sun) and back to the innermost regions of the solar system at *perihelion* (the closest point to the Sun). When comets get near the Sun, their frozen water and gases sublimate, turning directly from ice to gas. This forms a halo of gas, called the *coma,* around the nucleus. The coma is usually all that can be seen when a comet is discovered.

As the comet nears the Sun, sunlight ionizes its gas to form a plasma. Driven back by the outflow of particles from the Sun — the solar wind — the plasma forms a long and sometimes spectacular tail. Sunlight melts the comet's ice and liberates trapped dust particles, which are driven backward and form a separate tail of dust. The bright plasma tail always points directly away from the Sun. The dust tail, however, is curved — the heavy dust particles aren't pushed back very fast and tend to spread out along the comet's orbit.

According to presently accepted ideas, comets were formed at the outer edge of the original solar nebula at the same time as the Sun and planets. The gravitational influence of nearby stars slowly perturbed the orbits of these comets, and eventually they formed a huge spherical cloud. Astronomers believe that this Sun-centered shell of comets — called the Oort Cloud — extends out to at least 500 times the distance between Pluto and the Sun and contains about a trillion comets (see "Backtracking the Comets," ASTRONOMY, August 1982).

Over the eons, stars that happened to pass within a light-year or two of the Sun disturbed the randomized motions of these comets, sending some on their way into the inner solar system. Most comets entered long, elliptical orbits that bring them close to the Sun only once every several hundred thousand years or so. But some, because of close encounters with Jupiter or Saturn, became trapped in much smaller orbits that kept them within the planetary realm; they are called *periodic comets*.

A periodic comet usually shines brightly on its early trips into the Sun's vicinity, developing a long tail and becoming a prominent interloper in the night sky. But each passage near the Sun reduces its limited supply of frozen gases, and the comet gradually fades away until nothing but the rocks and dust that were once mixed into its nucleus remain. The show doesn't necessarily stop there, though. Eventually, this solid material spreads out along the comet's old orbit, and will provide yearly meteor showers if the Earth passes through the path of debris. (See "Comet Swift-Tuttle and the Perseids," ASTRONOMY, August 1983.)

Halley's comet is by far the most famous. It was the first recognized as being periodic, when Edmond Halley predicted its return in 1758. Unfortunately, Halley didn't live to see his prediction fulfilled. When he died in 1742, the "fireball thrown by God" theory was still in vogue.

Halley's comet is also fairly bright, as comets go. It orbits the Sun in a great ellipse that brings it to within 88 million kilometers of the Sun at perihelion and out beyond the orbit of Neptune at aphelion. The comet takes about 76 years to complete one orbit and has made at least 29 trips around its course since first being captured. Its first recorded appearance occurred in 240 B.C., its last appearance was in 1910, and it will return again in 1986.

Why do scientists study comets? And what is so important about Halley that several nations are spending millions of dollars to fly spacecraft out to it? According to Stephen J. Edburg of the International Halley Watch, the most important point about comets is that they are relics of the early solar system. Scientists believe that these small, icy balls have remained virtually unchanged since the solar system was formed, having spent most of their time in "cold storage" far beyond the orbit of Pluto. The only changes they've ever experienced are the periodic vaporizations of their outer layers on their close approach to the Sun. Comets can tell us a lot about the nature and composition of the ancient solar nebula, as well as the formation processes and early history of the solar system.

While astronomers have studied comets extensively from Earth, these long-distance observations have severe limitations. For examples, only those gases with bright emission lines can be clearly identified. We still don't know the actual composition of the nucleus, and we can only estimate the composition of cometary dust. The only way around these difficulties is to send measuring instruments through the coma and tail of a comet.

The ideal comet for close-up study would be one of the long-period types that takes hundreds of thousands of years to complete an orbit and has visited the inner solar system only a few times since it left the Oort cloud. Unfortunately, we never know when such "new" comets are coming. It would be impossible to plan and launch a space mission in the time between the comet's discovery and its perihelion passage, so we must make do with comets of shorter periods whose orbits are well known. The best candidate must be bright enough to study from Earth as well as from space and have an ample concentration of the gases and dust typical of new comets.

In general, the so-called "intermediate periodic" comets — those with orbital periods of several decades or more — meet our criteria best. Most have returned enough times for us to get accurate orbital and physical data, but not so many times that their nuclei are seriously depleted by solar heating.

As it turns out, only one bright comet of this type will pass close to Earth in the near future — Comet Halley. All other candidates are either too dim or won't return during this century. Another point in its favor is that a Halley flyby requires one of the lowest launch energies of any comet mission, allowing more sophisticated payloads.

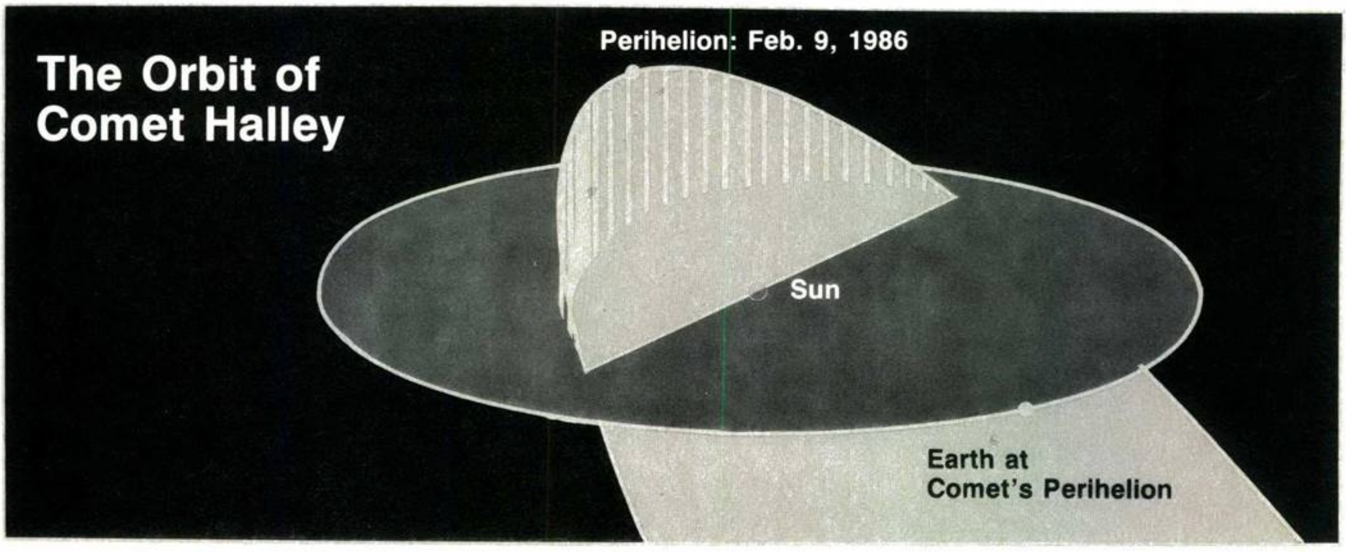
Several nations are now preparing for the next pass of Halley's comet. Japan, the European Space Agency, the USSR — all are building space probes to be launched in 1984-1985 for a flyby in March 1986. Meanwhile, astronomers everywhere are preparing for extensive ground-based and Earth orbit observations. The International Halley Watch will coordinate these efforts; it has already achieved its first major goal — recovering the comet.

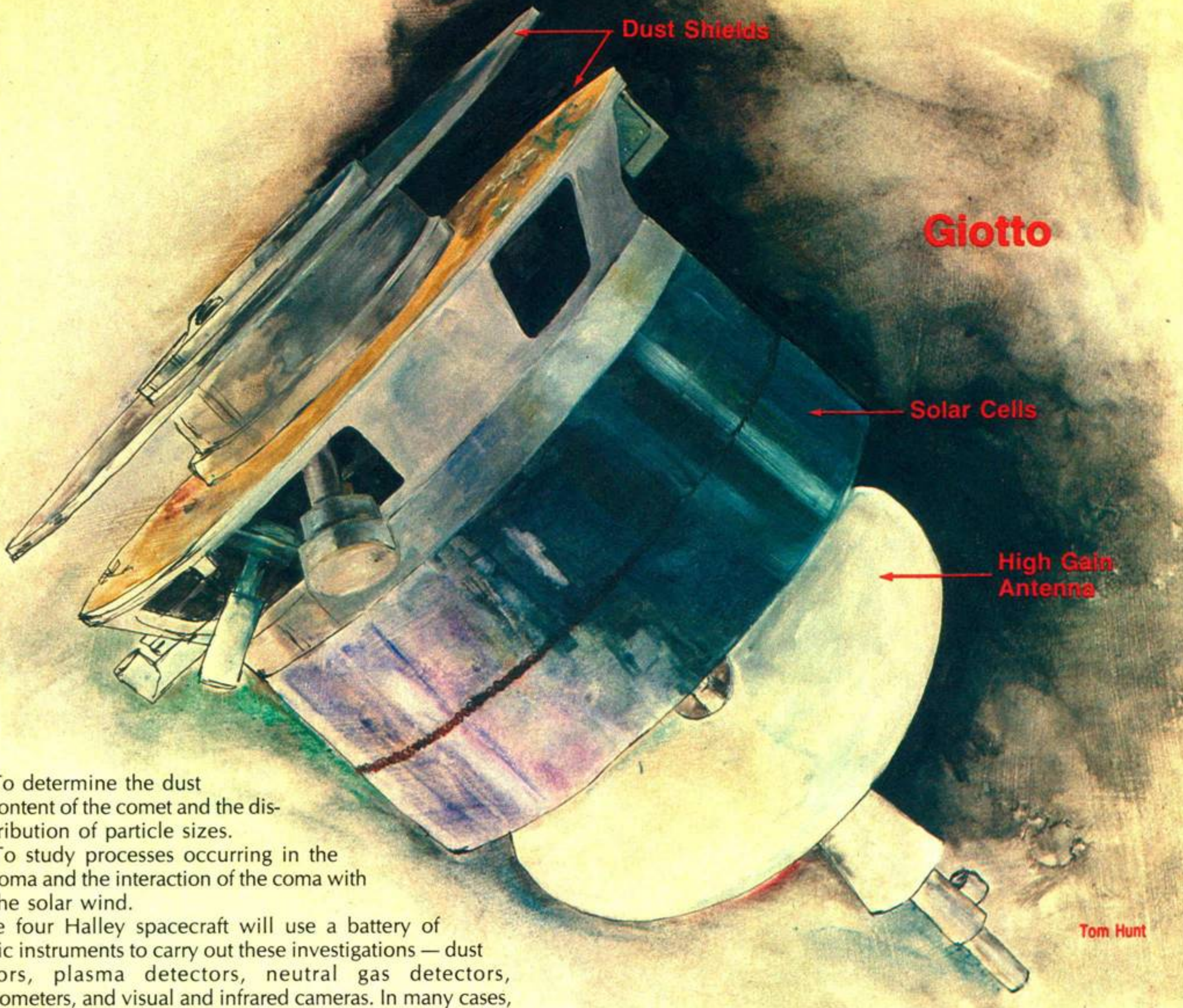
Although the United States has abandoned all plans for a Comet Halley mission, we will be sending a probe to fly by a different comet, Giacobini-Zinner, in 1985. This unique probe is the previously launched International Sun-Earth Explorer — a Sun-orbiting satellite with just enough leftover fuel to get into a flyby orbit.

The investigations of the Halley missions have three main scientific goals, all which will improve our understanding of the early solar system as well as of comets themselves:

- To determine the nature and quantity of the materials that make up the comet's nucleus.

The Orbit of Comet Halley





Tom Hunt

- To determine the dust content of the comet and the distribution of particle sizes.
- To study processes occurring in the coma and the interaction of the coma with the solar wind.

The four Halley spacecraft will use a battery of scientific instruments to carry out these investigations — dust detectors, plasma detectors, neutral gas detectors, magnetometers, and visual and infrared cameras. In many cases, measurements made by one probe will complement those made by another.

Giotto

Of the three planned Halley missions, the European Space Agency's is probably the most advanced. The Giotto probe is named after the Florentine painter Giotto de Bondone, who saw Halley's comet during its 1301 return and incorporated a realistic picture of it into a fresco that he painted inside the Scrovegni chapel in Pavoda. This is perhaps the first scientific "description" of a comet.

In July 1985 the spacecraft will be launched from the Kourou, French Guiana, launch complex in tandem with another payload aboard an Ariane launch vehicle. Sent into a high, elliptical orbit, it will be checked for damage. Then the probe will fire its onboard engine to inject itself into a Halley transfer orbit.

The spacecraft will remain in the ecliptic plane (the plane in which all the planets orbit) in order to save fuel. After a cruise lasting seven months, Giotto will reach its target on the outward voyage. On March 13, 1986, Halley will be 0.98 Astronomical Unit from the Sun and 1 AU from the Earth. (An Astronomical Unit is the mean distance between Earth and Sun — about 150 million kilometers.) Giotto should come within 500 km of the comet, passing it at a velocity of 68 km per second. Most of the scientific measurements will begin four hours before closest approach. The mission will probably end near closest approach, since it is likely that cometary dust particles will destroy the spacecraft. Because of this danger, data from the spacecraft will be sent to Earth right away, instead of being stored on tape for later playback.

Giotto is cylindrical in shape and stands almost three meters high. The craft will be stabilized by rotation, with its spin axis aligned with the direction of travel relative to the comet. A dust shield will intercept most of the oncoming dust particles. The dust shield consists of a one-millimeter sheet of aluminum backed by a separate, thicker sheet of Kevlar, a lightweight material used in bullet-proof vests and battleship armor. Two shell-like sections close over the engine nozzle after it fires, giving complete protection.

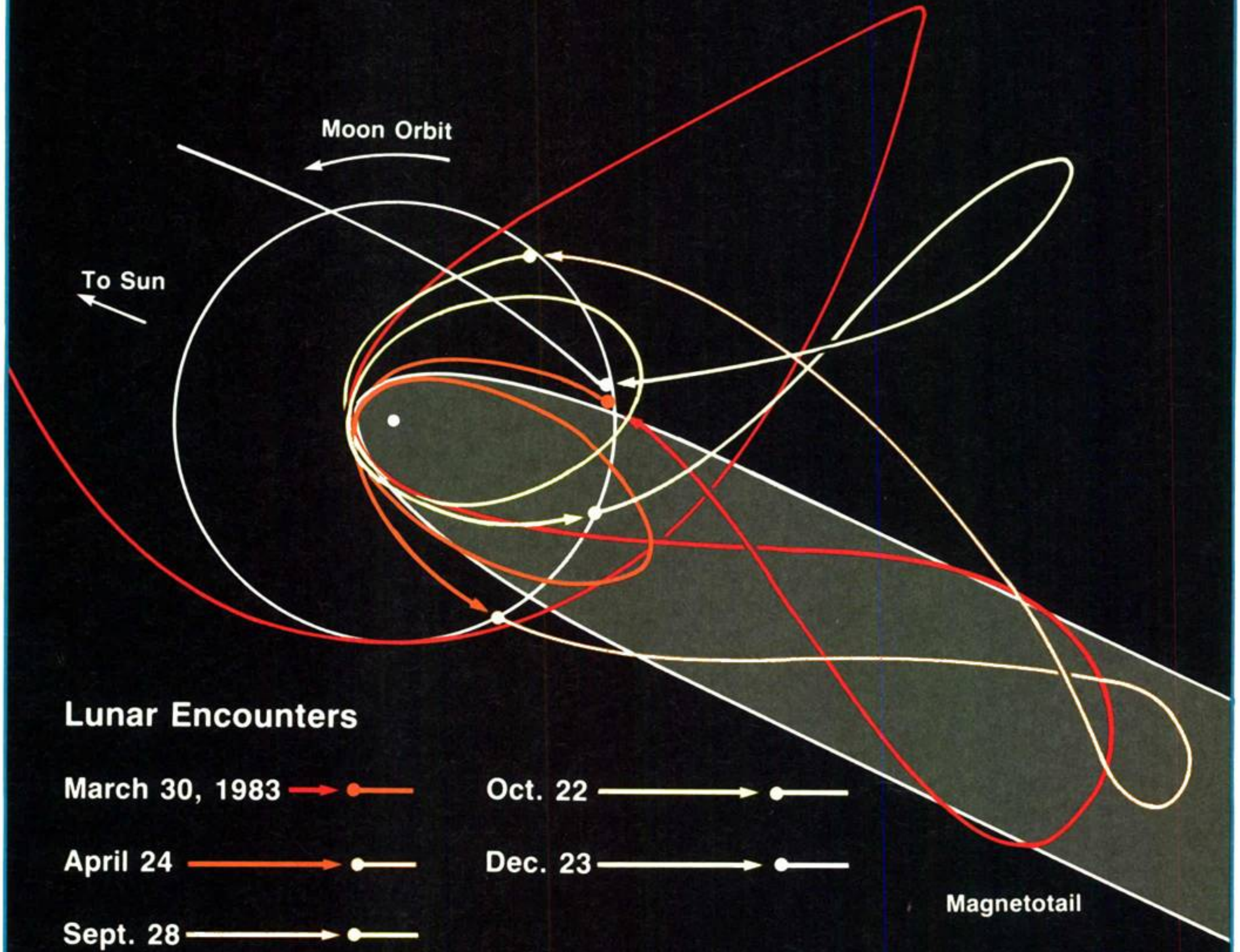
The spacecraft has three equipment platforms, two devoted to spacecraft systems and one to experiments. Most of the experiments will be mounted up front, behind the dust shield, with the exception of a magnetometer on a tripod, an optical detector that looks behind the probe, and some impact detectors on the dust shield itself.

Solar cells around Giotto's outside surface provide power. Unfortunately, they will not generate sufficient electricity to run all the experiments during the encounter phase and to make matters worse, they will probably be seriously damaged — perhaps "sand-blasted" — by dust particles. Four onboard batteries should provide full power under even the worst conditions.

The Giotto Mission is scientifically ambitious; its goals include finding out the composition of the coma and its chemical and physical processes, determining the composition of dust particles and the ratio of dust to gas, providing high-resolution images of the nucleus, and investigating the flow of ionized gas in the vicinity of the comet and its reaction to the solar wind. To accomplish these goals, Giotto will carry 10 scientific instruments, including a multicolor camera, a photopolarimeter, dust detectors, and several plasma experiments.

The Halley camera will be used to provide multicolor images

ISEE-3: Getting There Is Half the Fun



In August 1978, the third International Sun-Earth Explorer satellite was launched into the gravitational balance point between Earth and Sun. The spacecraft's original task was to monitor the Sun's "wind" of charged particles, but after four years of operation it began a new mission: a study of the Earth's magnetotail through 1983, a flyby of Comet Giacobini-Zinner in September 1985, and long-distance observations of Comet Halley in 1985 and '86.

ISEE-3's second life begins with what may be the most complex set of orbital maneuvers ever undertaken by a NASA spacecraft. The satellite doesn't contain enough fuel to catch up to the comets on its own, so mission planners sent it into a series of looping trajectories that will swing it past the Moon five times. Each lunar flyby gives the spacecraft a gravitational kick that increases its velocity and changes its direction. The last one, scheduled for December, brings it within 100 kilometers of the Moon's surface.

The probe will plunge through the tail of Giacobini-Zinner on September 11, 1985, passing within 3,000 km of the coma. ISEE-3's instruments will provide the first on-site measurements of a comet and its environment. Six weeks later, the spacecraft will move to the first of two locations upstream from Comet Halley. Its October 1985 approach places ISEE-3 138 million km ahead of the comet; the probe's March 1986 encounter takes it within 31 million km. From both upstream positions, the probe will observe the solar wind a day or so before it reaches Halley. Ground telescopes and the European, Japanese, and Soviet probes will then observe the interaction between this measured solar wind and the comet.

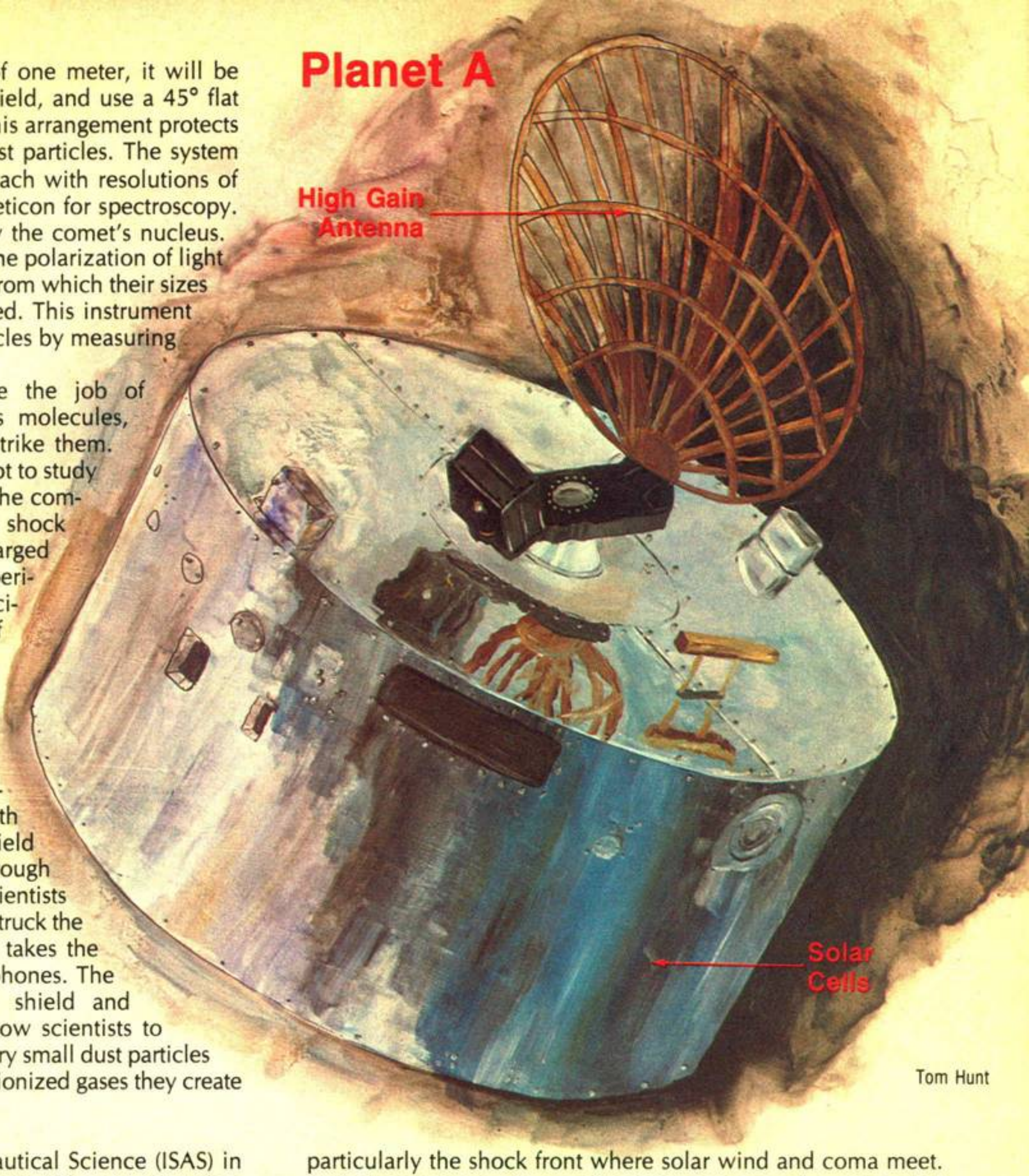
By 1987, ISEE-3 will be 120 million km from Earth. At this distance, 75 times greater than the range for which its radio transmitter was designed, even NASA's upgraded Deep Space Network will lose the spacecraft's signal. But ISEE-3 will return to near-Earth orbit in 2015.

of the nucleus. With a focal length of one meter, it will be mounted sideways behind the dust shield, and use a 45° flat mirror to look forward at the comet. This arrangement protects the camera from direct impacts by dust particles. The system will employ two television cameras, each with resolutions of 328 x 328 lines, plus a 2 x 936 line Reticon for spectroscopy. The camera can swivel 180° to follow the comet's nucleus.

A photopolarimeter will measure the polarization of light reflected from cometary dust particles, from which their sizes and other properties can be determined. This instrument can also determine the density of particles by measuring the amount of light they scatter.

Three mass spectrometers tackle the job of measuring the masses of neutral gas molecules, plasma ions, and dust particles that strike them. Several plasma experiments will attempt to study the interaction of the solar wind with the cometary "ionosphere" — particularly the shock wave between the Sun's flow of charged particles and Halley's coma. These experiments will measure the energies, velocities, directions of travel, and masses of the cometary ions. Meanwhile, a magnetometer will analyze the magnetic field within the coma.

Three microphones mounted on the outer dust shield will detect the impacts of large particles by the vibrations they create in the shield. A fourth microphone mounted on the inner shield will detect any dust particles that get through the outer one. With this information, scientists hope to determine where each particle struck the front shield by the amount of time it takes the vibrations to reach each of the microphones. The time between puncturing the front shield and impacting on the back shield will allow scientists to determine the speed of the particles. Very small dust particles will be detected indirectly, through the ionized gases they create when hitting a separate detector.



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Planet A

The Institute of Space and Astronautical Science (ISAS) in Tokyo plans to send a scientific probe called Planet A to Halley. Planet A will fly past the comet about five days before Giotto, on March 8, 1986. A test craft, called MS-T5, will be launched six months earlier to prove the capability of the launch vehicle and the Japanese deep space communications network, and to test out some new techniques for velocity control and positioning. But only Planet A will intercept the comet — MS-T5 will never get closer than 10 million miles and will take data on the interplanetary environment.

Launched from the Kagoshima Space Center in Southern Japan on August 14, 1985, a "kick motor" in the back of the probe will give it the extra boost needed to get into its Halley intercept trajectory. Unlike most interplanetary probes, Planet A will be boosted directly into its intercept orbit, instead of first going into a parking orbit around the Earth. This "direct injection" method saves fuel, but it has a disadvantage — the exact orbital errors of the spacecraft will not be known until it's well on the way. There is no final kick into an injection orbit, which would be able to compensate for these errors. As a result, the spacecraft's closest approach will be tens of thousands of kilometers from the nucleus.

Planet A is cylindrical in shape, about 0.7 m tall and 1.4 m wide. Like Giotto, Planet A will be spin-stabilized and will have a non-spinning high-gain dish antenna that always points toward Earth. Solar cells around the craft's outside will supply 82 watts of power during closest approach, at a distance of 0.82 AU from the Sun.

Planet A is designed to observe the coma's growth and decay, the velocities of the expanding cloud of hydrogen atoms around the nucleus, and the solar wind around the comet — particularly the shock front where solar wind and coma meet. Only two instruments, an ultraviolet camera and a solar wind analyzer, are aboard the craft.

The ultraviolet camera consists of an ultraviolet telescope, a charge-coupled device (CCD) camera with 125 x 150 line resolution, and related controlling electronics. The camera will have a 2.5° field of view and a resolution of one minute of arc — about 30 km from a distance of 100,000 km. This resolution will not be sufficient to resolve the nucleus (thought to be about 5 km in diameter) but it will be more than ample for detailed pictures of the structure of the coma. While Giotto photographs the nucleus "close up," Planet A will photograph the coma around it. In this sense, Planet A complements the European and Russian probes.

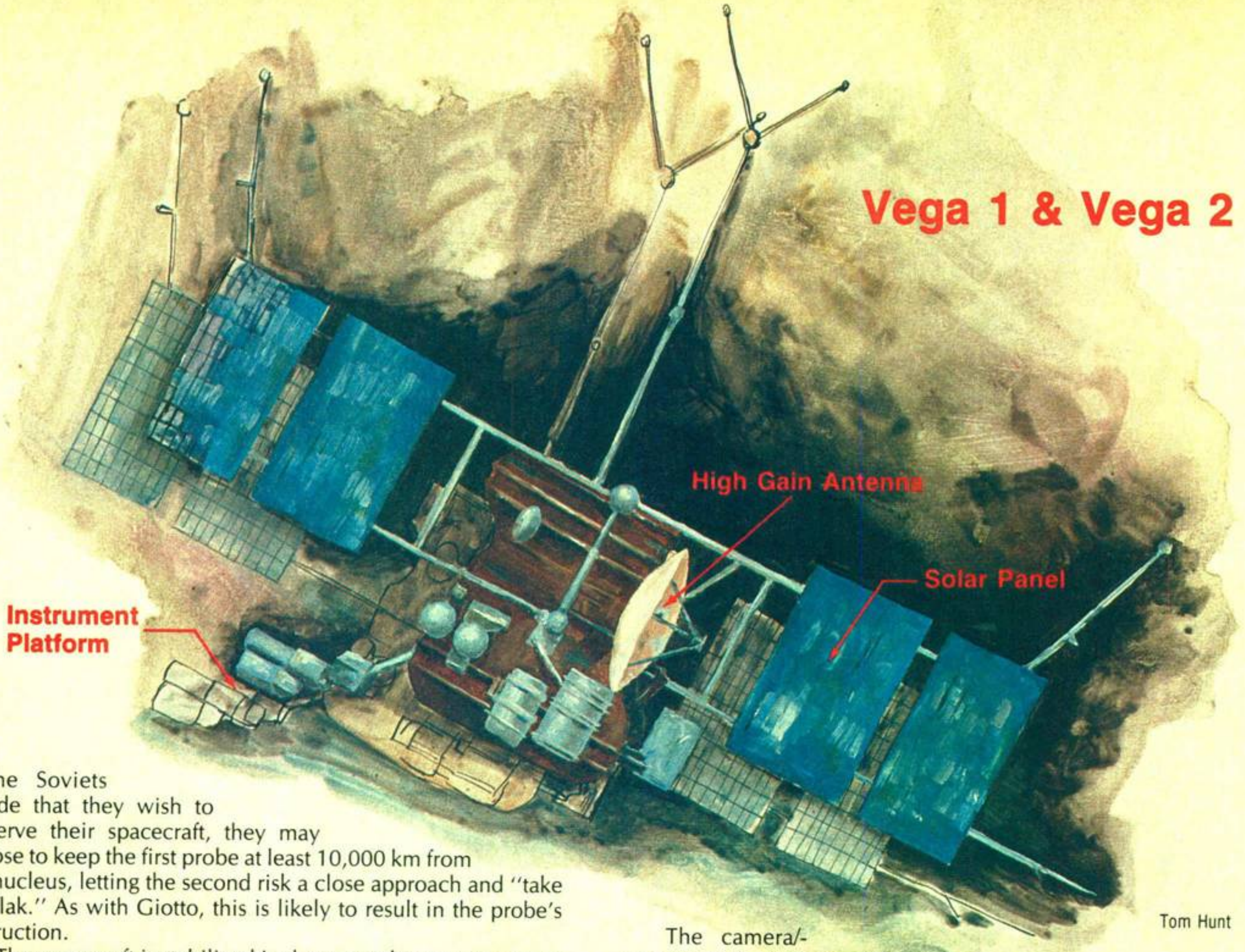
The second experiment, the solar wind analyzer, will measure the distribution and direction of the solar wind within 30° of the ecliptic plane. This detector is similar to a photomultiplier.

Vega 1 and 2

The Soviet mission to the comet is a combined Venus swingby-Halley flyby mission. (Vega is an acronym formed from the Russian name of the mission — *Ve*nera-*Ga*lley.) Two identical spacecraft will be launched between December 22 and 26, 1984. After carrying Venus landing probes to that planet in mid-June, 1985, the two spacecraft will use the venusian gravity field to kick them on toward Comet Halley. The first spacecraft will encounter Halley on March 8, 1986; the second will fly by about a week later.

Although the spacecraft can be targeted with a precision of about 100 km, the position of the spacecraft relative to the comet nucleus will be known only to within a few thousand kilometers.

Vega 1 & Vega 2



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If the Soviets decide that they wish to preserve their spacecraft, they may choose to keep the first probe at least 10,000 km from the nucleus, letting the second risk a close approach and "take the flak." As with Giotto, this is likely to result in the probe's destruction.

The spacecraft is stabilized in three axes by gyroscopes, so it can orient itself in any direction. Its main features are four large solar panels, a high-gain dish antenna, and an independently pointing platform full of cameras and experiments.

Able to rotate through 110° and 40° in two directions perpendicular to each another, the instrument platform has a pointing accuracy of five minutes of arc. It will carry narrow and wide-angle cameras, a spectrometer, and a combination camera and spectrograph. All other experiments are mounted in the spacecraft body, with the exception of some solar wind and plasma experiments mounted on a long boom. Again, a thin multilayer sheet set in front of a panel of aluminum 1 mm thick shields the spacecraft from high-velocity dust impacts.

The science data will be taken between 2½ hours before encounter to 30 minutes after encounter. Several 2-hour periods of data-taking will bracket the measurements made at closest approach.

The wide-field camera will photograph the coma and act as a finder for the narrow-angle camera to resolve surface features down to 200 m from a distance of 10,000 km. Both cameras will have resolutions of 500 x 500 lines, but complete images will not be transmitted. Instead, only a window one-tenth of the field's total area centered on the region of greatest brightness will be sent to Earth. Exposure times must be kept short to keep the images from blurring — the probe will be moving very rapidly.

In addition to the scientific objectives, the cameras provide information necessary to point the instrument platform. By photographing the comet prior to encounter, ground controllers can compute the spacecraft's precise trajectory relative to the comet's nucleus. This will enable them to aim the instruments properly during the brief encounter phase.

A spectrograph will be used to study the outflow rates and composition of cometary gases, as well as the polarization of light reflected from the dust particles. The spectrograph will employ a Cassegrain telescope with focal length of 500 mm and an objective 140 in diameter.

The camera/-spectrograph will provide spectral data and images of the nucleus in infrared light. Light coming through the Cassegrain telescope will be split into three beams — two for spectrography and one for images of the nucleus. These infrared observations will allow scientists to deduce the temperature of the nucleus, the nature, density distribution, and temperature of the dust particles, and the temperatures, content, and nature of the gas molecules.

In addition to the imaging experiments, Venera-Halley will carry several plasma experiments to study the masses, energies, and wave phenomena in the plasmas and neutral gases of the coma. A magnetometer will measure magnetic fields at the shock front between the solar wind and the coma. A dust-detecting system, similar to that used on the Giotto spacecraft, will measure the numbers, velocities, impact locations, and directions of dust particles hitting the shields.

These four spacecraft, along with Halley Watch Earth-based observations, represent an unprecedented degree of international cooperation in the exploration of space. Such cooperation is necessary if the four spacecraft are to complement each other in instrumentation and flyby distances. The only way researchers can take full advantage of their own mission is to coordinate it with the others and share the mountains of returned data.

Representatives of all the projects have been communicating regularly, staging a series of interagency meetings to discuss matters of mutual interest. Meanwhile, the International Halley Watch has been working hard to coordinate near-Earth observations with each other and with the space missions. Perhaps the 1986 pass of Halley's Comet *is* an omen — not of doom, but of greater international cooperation in the exploration of our solar system.

Jesse Eichenlaub is the President of the Independent Space Research Group, which is developing the Amateur Space Telescope, a freelance writer, and a part-time student pursuing a Master's degree in optics.

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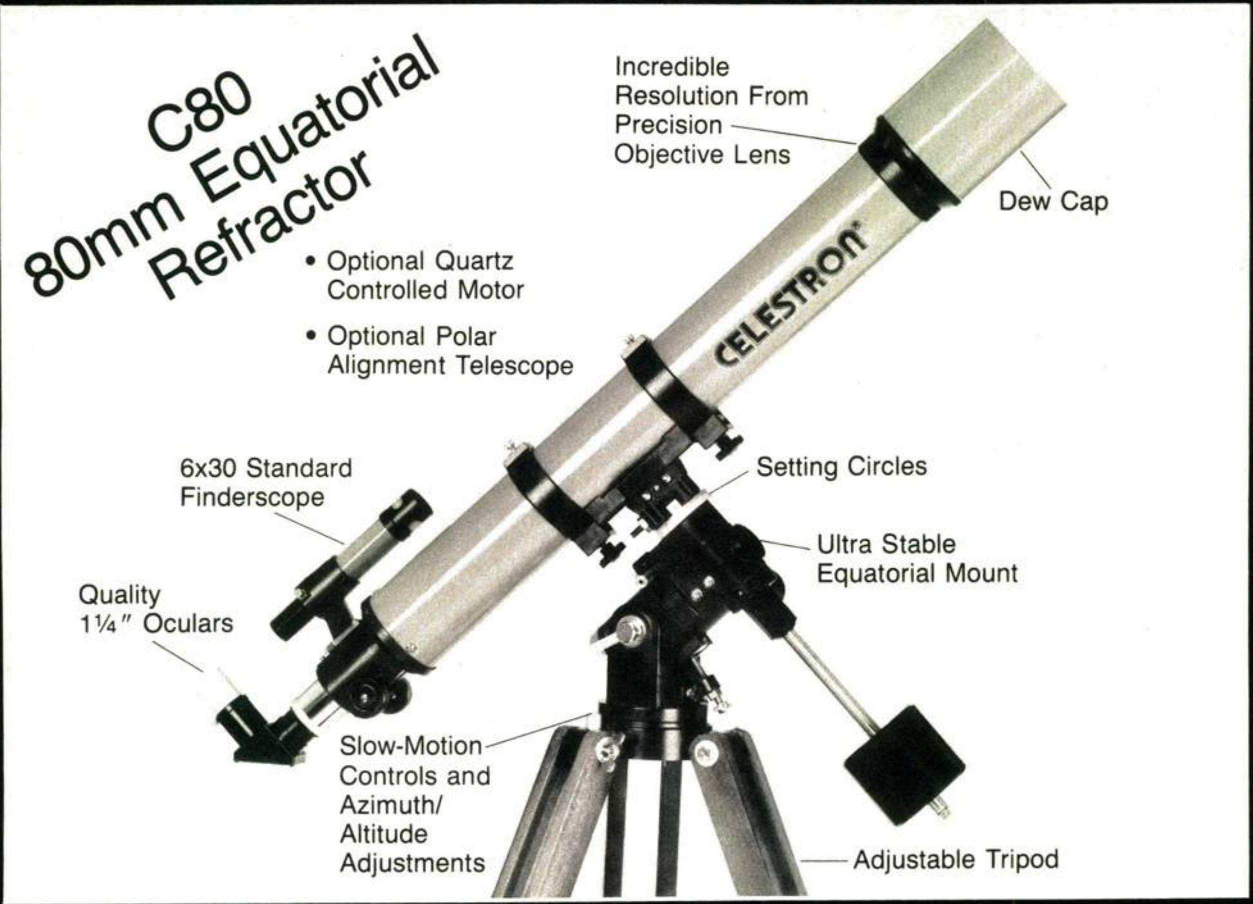
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Six Months on Mars Hill

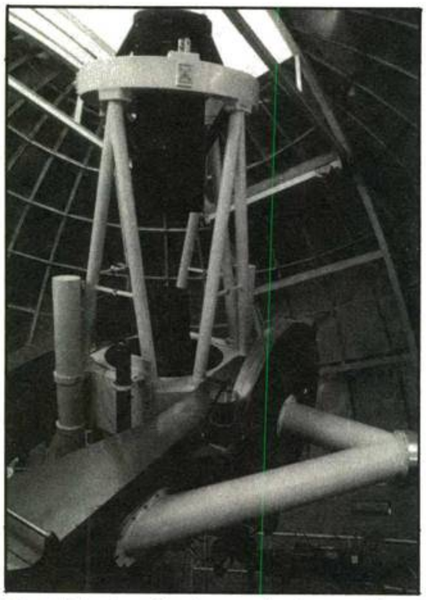
I've always been interested in astronomy, but being a resident of London makes it impossible for me to do serious observing. Up until the end of 1981, this remained a big dilemma. My aim is to become a professional astronomer, but my first and only telescope in London — a 60mm refractor — proved unsuccessful and soon disappeared into the attic.

To see whether or not I wanted to continue in my aim to become a professional astronomer, I wrote to about 25 observatories in America and Canada, asking to work for them for a while before going to university. Replies came trickling back, all polite refusals except for one from Flagstaff, Arizona. Dr. Arthur Hoag, the Director of Lowell Observatory, wrote a very friendly letter and mentioned that they might be interested. Further correspondence led to the offer of a job for about six months starting in January 1982. I was to taste what astronomy is all about.

On December 14, 1981, I left London for Vancouver, Canada, to spend Christmas with relatives. From there I traveled down to Flagstaff, arriving by Greyhound early one morning in the middle of a blizzard. Dr. Hoag himself met me at the bus station, and we drove up to the observatory, located about two miles away on Mars Hill. He then took me to the "Chalet," a bungalow 400 yards from the observatory which would be home for the next six months. For four months I had the place to myself; then visiting German and Canadian astronomers moved in, which led to interesting discussions.

The first few days were rather strange, but I met lots of people and soon felt at home. I discovered that I would be doing work for Dr. Edward Bowell, primarily in the field of asteroid discovery. I had three areas of duty: blinking plates, observing, and computing.

Blinking plates is an interesting job. By "blinking" two plates of the same region of sky — taken at different times — it's possible to detect the movement of solar system objects like asteroids. The first step is finding all the known asteroids predicted to be on the plate and marking them for computer checking. The second stage — looking for new asteroids — takes much more time. The whole plate must be systematically checked, which takes up to four hours per pair of plates, depending on the number of stars in the field. The procedure may sound straightforward, but there are pitfalls for a beginner like me: mistaking dust grains for asteroids or "Eastman-Kodak Objects" (plate blemishes) for comets. I had to be careful not to be too meticulous: every object that could possibly be an asteroid got marked. One day I spent a couple of hours checking only a small area on the plates and found an impressive cloud of objects. Then Dr. Bowell came in, commented on my lack of progress, and proceeded to eliminate nearly all of my newly discovered "asteroids" — most were dust grains or actual plate grain.


Brian Skiff

The 42-inch reflector on Anderson Mesa.

However, one object was confirmed as an asteroid and designated *W1*, a very exciting event. When I became bogged down with other plates and no discoveries, I could gaze at W1 for a while and continue the search, encouraged once again.

Blinking plates requires you to use your brain in a certain way, and it is hard work. It is difficult not to let your mind wander and lose concentration. It also gets boring, especially in regions of the sky near the Milky Way. But finding a single new object more than makes up for this and makes all the work worthwhile.

The computing part involved finding out why a program to reduce photometric data did not work. This meant learning FORTRAN for a start. The work was useful and gave me a chance to learn the ins and outs of using a large computer, although I soon developed a strong dislike for FORTRAN.

Luckily, I had the chance to do some observing at Lowell Observatory's dark sky site about 14 miles southeast of Flagstaff. Here are four telescopes: 31-inch, 42-inch, and 72-inch Cassegrain reflectors, and the 13-inch "Pluto Camera," the wide-field survey camera used by Clyde Tombaugh to discover Pluto in 1930.

The 13-inch camera is now used for Dr. Bowell's asteroid program. I went out to the camera a few times with observer Brian Skiff. As an introduction to using telescopes, I controlled the

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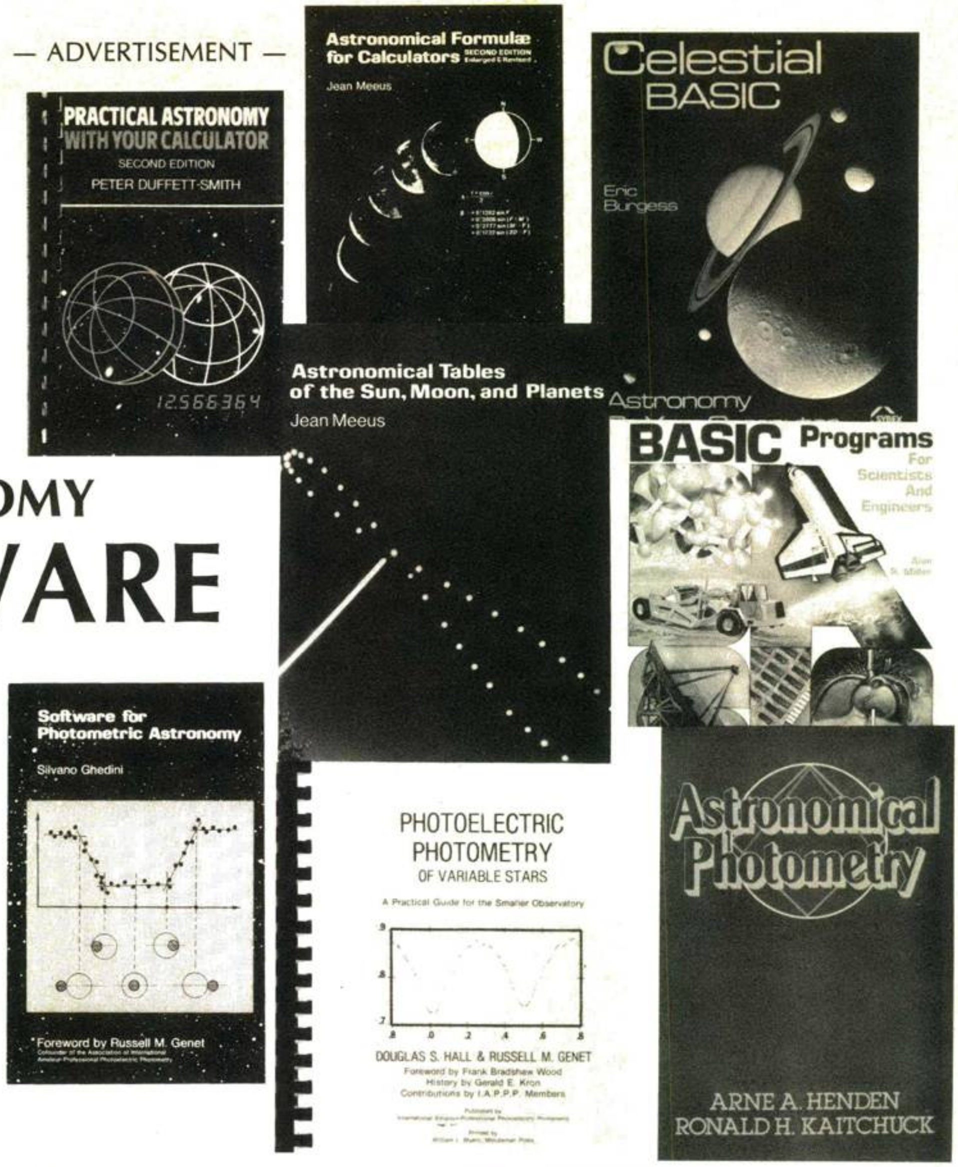
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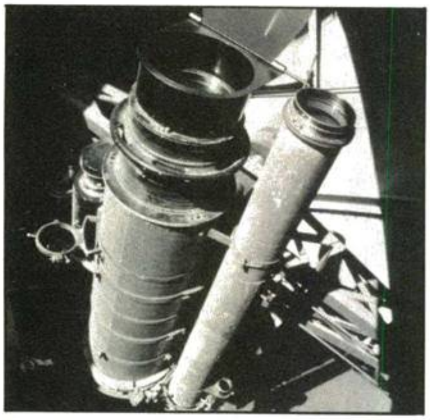
31-inch. It is surprisingly simple to operate a big telescope. Everything is done automatically with just a few buttons. Although old, the 72-inch is a stunning telescope. It is controlled from a warm room in the dome using a TV monitor and is used a great deal by visiting astronomers. I did most of my observing on the 42-inch, a beautiful telescope only about 15 years old. It is housed in its own dome up two flights of stairs with a warm room near the entrance. My first views of the planets through it — especially Jupiter and Saturn — were quite amazing. I spent most of my observing time doing photometry of asteroids in runs of four to ten nights around New Moon. I spent a total of 25 nights on this photometry.



Brian Skiff

The 13-inch "Pluto Camera."

A typical night's observing proceeded as follows: about an hour before dusk I collected the car assigned to the telescope, drove it up to the Chalet and loaded it with all the essentials for a night's observing — food, paper, woolen socks, coat, and scarf — and set off for the Mesa. By this time I became accustomed to driving on what is for me the wrong side of the road. If I left early enough I could watch the Sun set over Lake Mary from the road leading to the observatory. By now it would probably be dark outside, although not yet photometrically dark. Astronomers opened the dome by pressing a button and then uncovered the primary mirror. My next task was setting up the photometer. The equipment consists of a high-voltage power supply, the photometer itself, an amplifier, and a digital counter to record the number of photons we collected.

The equipment takes a while to settle down, so the next step was locating the objects. Originally I used star maps to help in locating the objects, but the maps often did not resemble what I saw through the eyepiece. After finding out that I had spent a whole night measuring a 13th magnitude star instead of the intended asteroid, I just plugged in the computer-predicted coordinates of the asteroid, pointed the telescope, and looked. I found that the telescope pointing accuracy was usually good enough for the asteroid to be right on the crosswires after checking with the exact positions of nearby stars.

The observing procedure involved alternately measuring the brightness of the asteroid and a nearby comparison star. Photons from the asteroid recorded on the photomultiplier readout in periods of 10 seconds, which I diligently copied down. After about six count periods, I offset the telescope and measured sky brightness. The same measurements are made for a nearby standard comparison star, to correct for variable transparency through the night. We repeated this procedure throughout the night, occasionally taking breaks on the catwalk, gazing up at the stars.

Standing outside for eight hours in the middle of the night while copying numbers off a small display may not sound like the ultimate pleasure in life. But for some reason it is fun. Maybe it is the excitement of doing something that nobody else has done, maybe just a feeling of being at one with nature. Or the amazement of thinking about photons which probably left the stars long before I was born, ending their long journey on a night when I was there to greet them.

While in Arizona I did some sightseeing and enjoyed the Barringer Meteor Crater and the Grand Canyon, among other stops. The most impressive place was Havasu Canyon, a side-arm of the Grand Canyon where I camped overnight with Dr. Hoag and Dr. Bowell.

Dr. Hoag, his wife, and everyone else at Lowell were very kind, patient, and friendly and made my stay in Flagstaff a wonderful experience for which I am grateful and which I shall never forget. I came away with a "pizza-addiction," as well as a strengthened desire to become a professional astronomer. And hopefully — someday — I shall be able to return to Mars Hill.

Martin Watt
Surrey, England

Observing with the Soviet Union's 6-Meter Telescope

I had visited the observatory once before, in 1973, before the 6-meter mirror had been placed in the BTA (Russian initials for Big Alt-azimuth Telescope). But in August 1980, along with Nikolai Samus of Moscow's Sternberg Institute, I visited the Special Astrophysical Observatory (SAO) in the Caucasus Mountains, this time as an official observer on a spectroscopic study of horizontal-branch stars.

We wanted to use the 6-meter telescope because it has a spectrograph that can reach stars of 16th magnitude and disperse the light onto a photographic plate at a scale of 28 Angstroms per millimeter. In our first summer, we used this equipment to take spectra of some brighter stars, the so-called field horizontal-branch stars, and then some faint blue horizontal-branch stars in five different globular clusters. These are both types of stars that have settled down after the initiation of helium fusion in their cores. These interesting stars are members of Population II, the first stars to form in the young Milky Way Galaxy some 10 to 15 billion years ago.

By studying stars of this type, astronomers hope to learn more about conditions at the time the Galaxy formed and how stellar evolution proceeded from that time to the present. Our observations will add data to help us understand such questions. By measuring the intensities of faint lines in their spectra, we could derive information about the abundances of many elements in the atmospheres of the stars.

Several foreign astronomers have used the 6-meter in the past few years. A group of astronomers from England used a special camera to photograph quasars detected in radio surveys. It was left at the SAO for some time after the observing run and was used by Soviet astronomers. Four groups of French astronomers have used the BTA — they've made studies in the infrared, taken spectra of galaxies, obtained UV spectra of carbon stars, and done speckle interferometry. A West German group has obtained infrared photometry of quasars. East German astronomers obtained spectra at 100 Angstroms per mm of the best quasar candidates. In 1981 an Italian group obtained spectra of SS 433, the exotic star that shoots high-velocity gases toward and away from the Earth simultaneously. But our proposal for observing time was the first to include an American.

Until recently, the work done on the 6-meter was performed chiefly at one of the two Nasmyth foci, located in the fork arms on each side of the telescope. Light is reflected from the primary to either side by a 45° flat mirror. The prime-focus cage is a large cylinder at the top of the telescope. Many astronomers use the prime focus these days, and about half of the

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The other Nasmyth focus holds a German spectrograph with an image tube, a scanner used chiefly for planetary spectra, and a high-dispersion (12 Angstrons per mm) scanner that works on stars between 10th and 13th magnitude. A fast photometer can detect the arrival of every photon and see changes that take billionths of a second to occur. It is used to study rapid variations in brightness, storing its information on magnetic tape for later analysis. Astronomers can make photoelectric scans with a magnetometer used to study variations in magnetic stars.

To reach the SAO, I flew from Moscow to Mineralniye Vody, in the Caucasus region of Russia, from which I made the 3½ hour drive to the observatory. The offices in Zelenchukskaya have been moved to a large building at the bottom of the mountain since my last visit. The building also contains several apartments and even a nursery school for the children of the many astronomical families living at the site. At the office building, my partner Nikolai and I obtained passes to the 6-meter dome; we then continued up the mountain to the dormitory.

We spent the first few days before *our* 1980 observing run testing various photographic materials and checking the focus of the spectrograph and image tube system. We spent one night away from the observatory at a resort hotel at Dombai, in the Caucasus Mountains, a trip kindly arranged by the observatory's director. In our absence, Dr. Alekseev, the SAO astronomer in charge of the spectrograph, continued the focus and emulsion tests. When we returned, we decided to use a Soviet fast film instead of the IIIa-J plates donated by the Cerro Tololo Observatory. Although the Cerro Tololo plates had a much finer grain, they were more than six times slower and the exposures we required would have been prohibitively long.

The predicted exposure times were correct for our first targets, the star HD 161817 and some blue horizontal-branch stars in M-13, but the spectra weren't resolved well enough to show the faint metal lines that interested us. So we switched to the main spectrograph on the other Nasmyth platform to take spectra of the brighter field horizontal-branch stars. The SAO astronomer in charge of this instrument came up the mountain to set up the telescope for us.

To use the main spectrograph, one observer sits in the main control room and enters the coordinates of the stars into the telescope's computer. The instrument automatically sets on this position. Another observer sits at the Nasmyth station and centers the star in the finder eyepiece. Starlight then falls onto the slit of the spectrograph and the photographic plate is exposed. While someone changes the plate holder, the telescope can be moved to the next program star. Since the 6-meter is an altitude-azimuth instrument, it never gets into an awkward position when observing stars at large hour angles. But you've got to be careful not to let it enter a zone within 5° of the zenith — the telescope cannot track a star through this region because the guide corrections sent to servomotors become too large and the telescope can't respond. An astronomer who lets the instrument track into this zone must stop his exposure.

The field of view through the main finder at the spectrograph has a diameter of about three minutes of arc, so an observer must have good positions to start with. Precessing the 1950 positions of star catalogs to 1980.6 gave us coordinates that placed the star in the field of view of the finder. Watching through the finder as the telescope moves to a new position is a strange experience to someone used to an equatorial mount. Unlike the view through an equatorially mounted telescope, where stars will move up and down or right and left, depending on the button pushed, the stars streak across the field at any angle. Every once in a while a bright star would race through the field. In a few cases it was so bright through the finder that I felt I should not look directly at it — an indication of the 6-meter's great light-gathering power.

The telescope makes some distinctive noises as it operates. The conversion of altitude, azimuth coordinates to right ascension and declination is done several times a second, and the noise of the motors turning the telescope in altitude and azimuth sounds like a high wind through trees. The suspension system contains oil under high pressure that quite often spurts up, splashing back into a pool of oil with a sound reminiscent of a fountain of water. The dome automatically follows the telescope as it tracks a star, but the motion is so quiet that it is scarcely noticeable.

In the latest observing run, Nikolai and I obtained scans of about a dozen blue horizontal-branch stars in three globular clusters. Computers at Union College are now reducing the data. Preliminary reductions of some of these stars indicate that measurements from our standard stars are repeating to within two percent. We were trying only to measure the calcium K line in our program, but we've found that about a dozen additional spectral lines show up. We'll be able to estimate the abundances of elements like iron, titanium and magnesium. The very fine spectra we obtained on the main spectrograph in 1980 helped us to identify the weak lines in our most recent spectra. With its main spectrograph and TV scanner, the 6-meter telescope is a most effective instrument — we easily obtained data that would be difficult to collect almost anywhere else.

The astronomers at the SAO could not have been more helpful in making our observing runs successful. From spending several nights working with us at the telescope to tracing a spectrum and identifying many of the standard lines, everyone went out of his way to help us. We deeply appreciate their efforts and hospitality.

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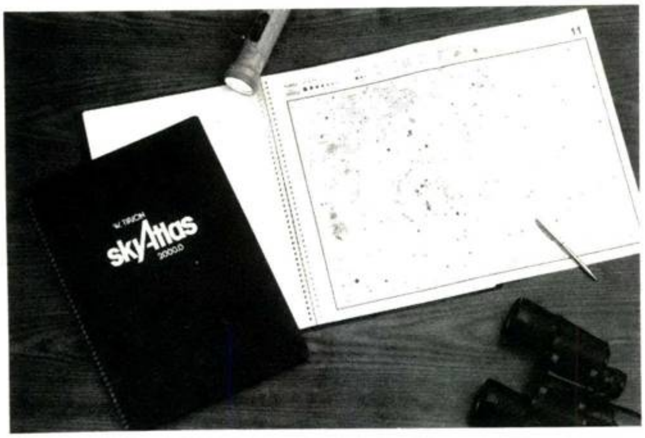
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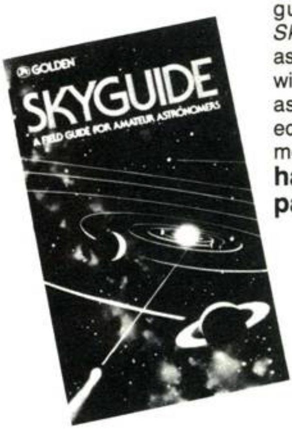
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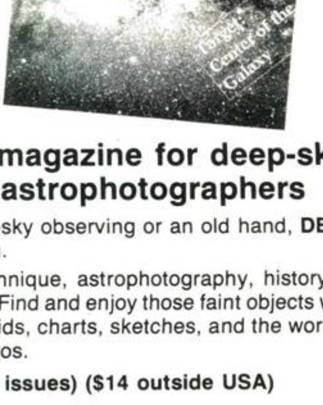
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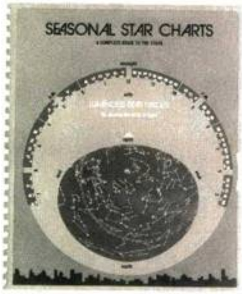
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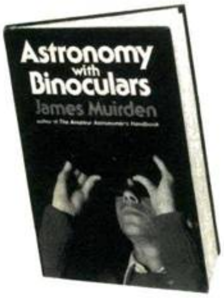
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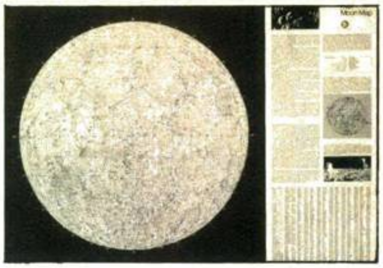

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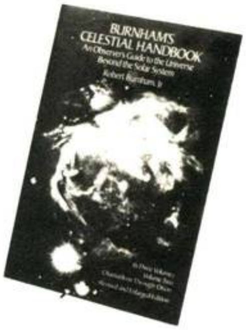
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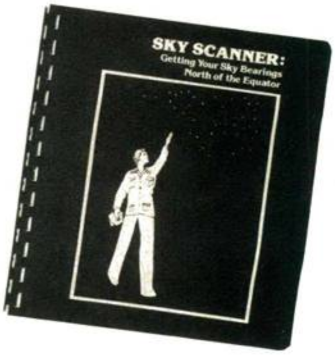
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ASTRONOMY
IN FOCUS

"... in peace for all mankind."

Sir / In reference to Mr. Port's letter "Who's for Mars" (In Focus, July), I wish he would name a single rational justification for his mind-boggling identification of the U.S.A. as the "greatest threat to peace and civilization." But apart from that, I want to address the more specific complaint he made about Bruce Cordell's daring speculation that the first Martians will not be Scottish, and the distaste with which he regards that assumption.

Perhaps Mr. Port is not aware that *American* artifacts left on the Moon bore the message, "We came in peace for all mankind," or that the Voyager mission will be carrying an hour and a half of the *world's* music as it becomes the first human object to leave the solar system. (Moreover, the music wasn't just Western; other forms, such as Hindu, are there as well.) When my son asks me why the U.S. was so unselfish when no one else contributed a penny to these efforts, I frankly cannot give him an answer.

Mr. Port, if we are, as you say, developing an "undercurrent in American society" of which you disapprove, the explanation may well lie in the indignation aroused in many of us by reading such letters as yours!

Leslie B. Wagle
Greensboro, NC

Two Astronomy Days?

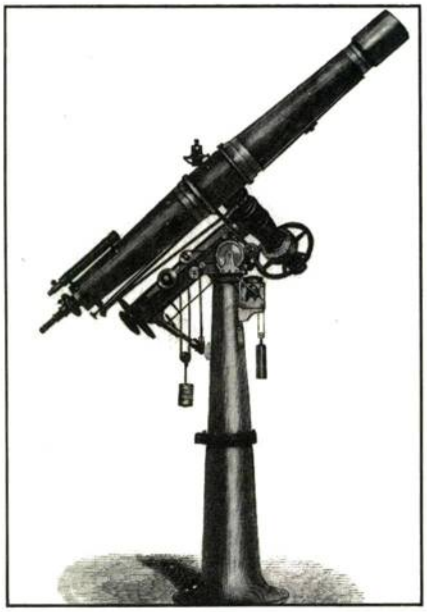
Sir / I noted recently in ASTRONOMY's AstroCalendar that Astronomy Day this year was scheduled for two different dates — April 23 and May 14.

Undoubtedly, amateurs have selected other dates for the observance of Astronomy Day due to local circumstances.

But wouldn't it be nice if we could all celebrate a national Astronomy Day where possible? This would do much to organize amateur astronomy toward the common goal of acquainting the general public with astronomy. Publicity would be on a national scale.

Perhaps then we can plan for an organized campaign to curb light pollution. We have only to gain a dark night sky for ourselves and for future generations.

Rick Kurczewski
West Paterson, NJ



Has Anybody Seen a Telescope Like This?

Sir / We at the California Academy of Sciences are trying to restore California's first observatory refractor and need to study another telescope of the same style. Ours is a Fauth Model No. 72 made in 1876 (see above). If you know where such a telescope might exist, please contact Allan Wilson at the California Academy of Sciences, Golden Gate Park, San Francisco, CA 94118. Our phone number is (415) 221-5100, extension 236.

Allan Wilson
San Francisco, CA

Neutrinos and Supernovae

Sir / I recently picked up an issue of ASTRONOMY (Feb. '83), and became interested in the article "From Chaos to Consciousness." However, I soon encountered an apparent contradiction to my knowledge of physics (granted, a finite quantity) regarding the behavior of neutrinos in the evolution of neutron stars.

It is not clear to me how a massless particle is capable of applying a pressure on a surrounding medium, when due to its absence of mass, it is neither subject to any force, nor capable of imparting momentum to other particles.

Guy Rodrique
Nanaimo, British Columbia

— Particle physicists are presently attempting to determine whether or not neutrinos have mass. Several recent experiments suggest that the zero-rest-mass neutrino may not exist.

That aside, neutrinos do interact with matter, especially when the density is extremely high. Computer models of stellar collapse indicate that densities greater than 100 billion grams per cubic centimeter occur in the cores of massive stars. Although the idea of neutrino-induced supernovae has been popular since 1966, more recent work suggests that these particles are actually trapped in a collapsing star's core. Neutrino entrapment might stiffen the core against further collapse. This sudden stiffening could produce a violent shock wave ripping apart the star's outer regions. As yet, no one knows for sure, and there are many ideas of what goes on in a collapsing star.

Another Explanation

Sir / I was interested to notice that the Backyard Astronomer feature on Canes Venatici gave the widely quoted "probable" explanation for the name Cor Caroli.

The name is associated with Charles II, rather than his unfortunate father. Tradition has it that on the day of his restoration, May 29, 1660, the star either brightened or reddened noticeably. The story may be purely apocryphal — but the name stuck.

Why the star became known as Charles' Heart in particular is unclear. However, Charles must have had a large heart — there was room in it for many women!

Rob Moseley
Earlsdon, Coventry
United Kingdom

"Space" Blooper

Sir / Dorothy Beetle's proposed anthology of astro-bloopers (In Focus, March) might be enhanced by the addition of one from James Michener's *Space*:

"But it was not until just before dawn that he saw what he had left his bed to view. It was red Arcturus rising from the prairie . . . . At dusk he had seen Arcturus slip away from him; at the conclusion of the same night, he was witnessing its return to the heavens." (page 53)

Check me if I'm wrong, but I don't think stars make such radical positional changes with respect to the Sun in just one night!

Chad Boliek
Abiquiu, NM

Sir / While literature indeed abounds in astro-bloopers, I believe James Michener is correct when he claims that his character (John Pope) saw Arcturus set and rise again within the space of one night.

Checking in the planetarium, I found that between the approximate latitudes of 40° N to 60° N, Arcturus would be visible both after sunset and before dawn in October. And a prairie location with an unobstructed horizon would be just about ideal for seeing this phenomenon.

Vega in December and January, and Capella in May are two other bright stars that can be seen setting and rising in the space of one night. It is not the stars making "radical positional changes with respect to the Sun in just one night," but the effect of the Earth's rotation we are observing. The closer a star is to the North Celestial Pole (short of actually being circumpolar), the shorter the time it spends below the horizon.

Dorothy Beetle
Director, Patterson Planetarium
Columbus, GA

Russians Not First?

Sir / While I agreed with the review of *Space* in your April 1983 issue, the reviewer quotes Michener that the Russians got to the Moon first, landed first, got samples first, and photographed the farside first.

It is true that the Russians got there first: Luna 2 crashed on the Moon in 1959. They also photographed the farside first, with Luna 3 in 1959. They were the first to orbit the Moon (Luna 10 in 1966) and the first to softland with Luna 9 in 1966. However, they were *not* the first to get samples. Apollo 11 returned the first lunar samples in July 1969, and the Russians didn't get their first few grams of lunar soil until Luna 16 in September 1970.

Robert N. McCullough
Ferris State College
Big Rapids, MI

New Solar Observing Group

Sir / The Association of Lunar and Planetary Observers (ALPO), a worldwide organization of amateur and professional astronomers who observe solar system objects, has founded a section for observing the Sun. The work of ALPO's Solar Section will be visual and photographic studies of the structure and evolution of solar phenomena in white light. (While monochromatic observations — Hα, for example — will be accepted and kept on file, such observations will be used to augment those done in white light.)

Eventually, we hope that the Section will have enough observers around the world in both northern and southern hemispheres so that we will have continuous coverage of the Sun's activities. We invite anyone interested in joining us to write.

Richard Hill
Warner & Swasey Observatory
4632 E. 14th St.
Tucson, AZ 85711

Walter H. Haas
ALPO Director
Box 3AZ
University Park, NM 88003

behind the scenes | chasing eclipses

Eclipses seldom happen in convenient places. Yet wherever they happen — the middle of the Atlantic Ocean, the prairies of Manitoba in midwinter, the Indonesian archipelago — that's where we must go if we expect to see them. Four times in the last twenty years I've traveled to that narrow path where the Moon's shadow would fall, and three of those times the sky has been cloudy. Thus, despite having looked at thousands of eclipse pictures submitted to ASTRONOMY, I had never actually seen the corona. (Well, not quite — I got a three-second-long glimpse of it through cloud in Maine in 1963, just after the end of totality.)

But on June 11, this year, I saw some 311 seconds of totality from central Java. I've described the experience of that day in this month's Gazer's Gazette, along with a few of the pictures I took. (Unfortunately, our production deadline this issue made it virtually impossible for anyone who did not fly straight back from Indonesia, process and print his or her own film, and then immediately mail the resulting slides or prints to us to have any pictures in this issue. We promise more next month.) I hope that if you have never seen an eclipse, my little article will help you to imagine what it's like.

When's the next eclipse? Though it won't be total, an annular eclipse on May 30, 1984, crosses the southeastern United States. But it really isn't until July 11, 1991, that a long eclipse occurs within easy reach of the U.S.; it crosses Mexico and Central and South America. (If you want to know more about eclipses worldwide, refer to Fred Espenak's article in the June 1982 issue; for North American eclipses, see the June 1980 issue.)

Finally, an editorial footnote. Last month, with our August issue, ASTRONOMY began its 11th year of publication. Some people have told me that we should trumpet it from the rooftops. "After all," they've said, "you deserve it." But I prefer to think that the fact that we've become the world's largest astronomical magazine is proof enough of our worth; and on behalf of all of us here at ASTRONOMY, rather than tooting our own horn, I'd like to thank all you readers for supporting us these last 10 years. Without you, we couldn't have done it.

Sincerely,
Richard Berry
Richard Berry
Editor

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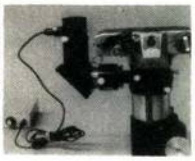

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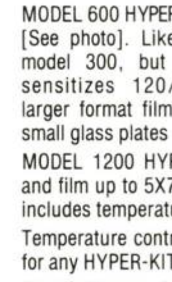

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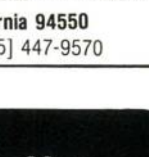

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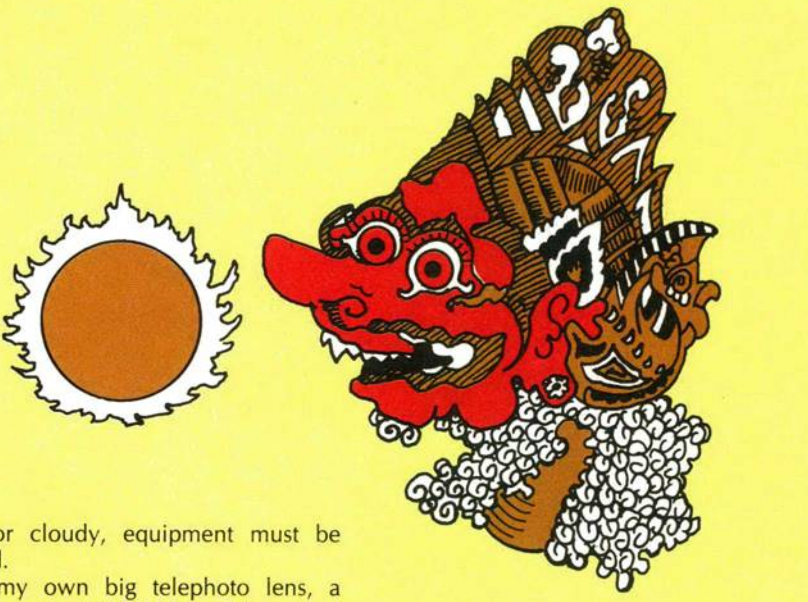


Total solar eclipse in Java: June 11, 1983. Wake up at 4:30, bags out by 5:00, eat breakfast, meet in the lobby at 6:00. We board our buses sleepy-eyed; a police escort, lights flashing, leads our caravan through the early-morning streets of industrial Surabaya and into the countryside, two and one-half hours past fields of rice, bananas, sugar cane, and fishfarms to Tuban, a coastal fishing village on the Java Sea, and right on the central line.

We North Americans are ordinary people at home, but here, halfway around the globe, we find ourselves honored guests of the town. But dancing, free beer, a cosmetics and fashion show, even the gracious words of the mayor of the town and the regional director of tourism cannot relax these guests — people intent on keeping a cosmic rendezvous with the shadow of the Moon — and time is passing. We've come halfway around the world for five minutes of totality!

Finally, with first contact less than an hour away, the buses depart to our observing site, a field behind the Kwan Sin Bio Chinese Temple. We park across the street, just yards from the Java Sea. To the east of the temple is a mosque; to the west, a small family farm. Indonesian soldiers and police patrol the area; members of a Chinese eclipse group watch the Americans. We unload our gear, traipse camera-laden through the bedragoned temple gates, past incense burners, painted statues of lions, little pagodas, and into the observing area, a grassy field with a large, walled fishpond in the center. We start setting up tripods, unpacking still cameras, movie cameras, welder's filter glass for observing the Sun. The soldiers watch, both friendly and curious.

The weather is humid and hot. Towering cumulus clouds build inland; near the coast, where we are, the sky remains free of cumulus. A high cloud deck, which seems to be moving slowly westward, spreads across half the sky. To the east the sky is blue and clear. But now there is no time for reflection; whether it's clear or cloudy, equipment must be readied.

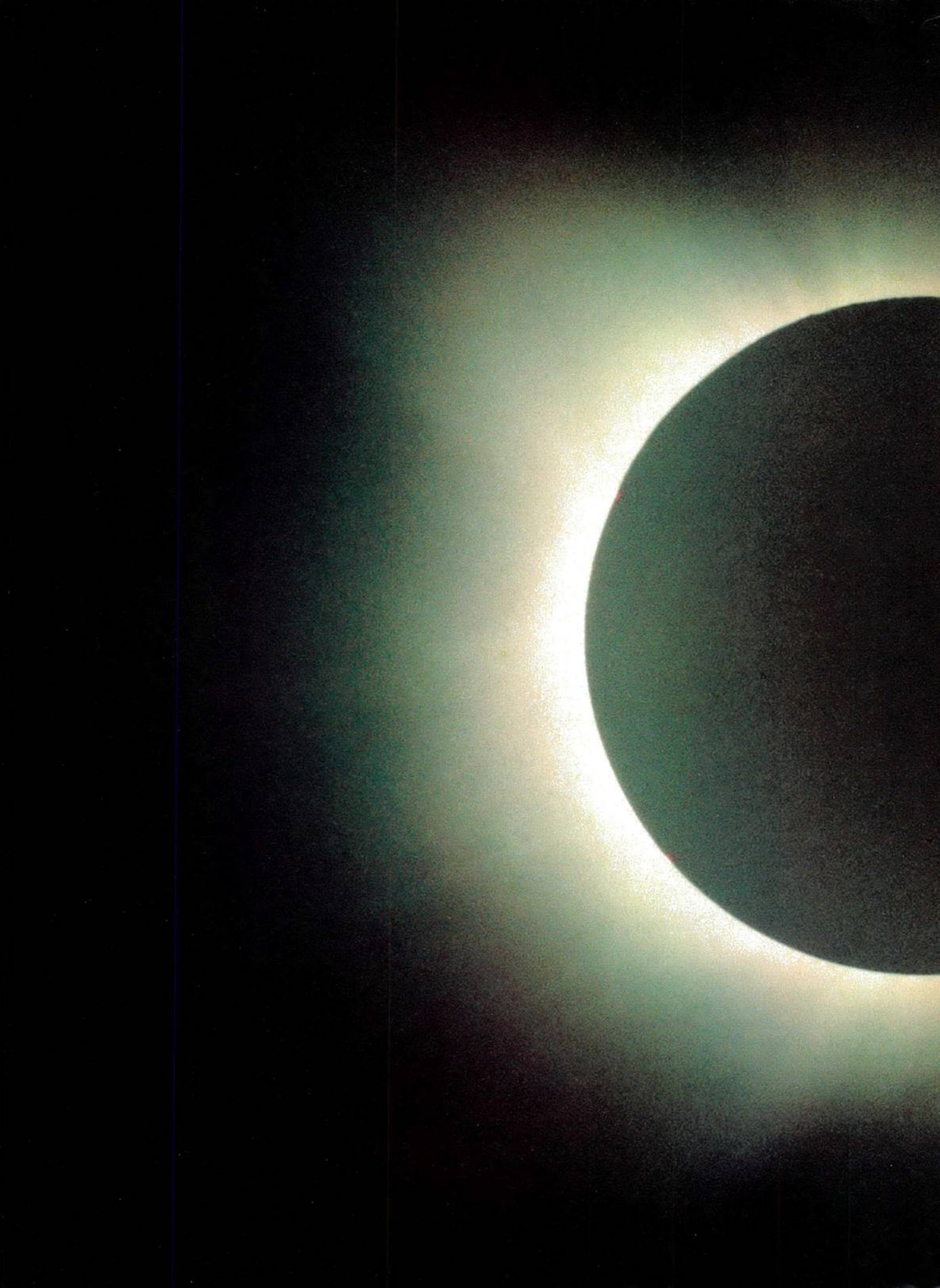
For my own big telephoto lens, a Russian-made MTO-1000 with a focal length of 40 inches, I need a firm flat surface. The wall of the fishpond looks ideal. I set down my equipment box and camera bag, spread the plastic ground sheet, then assemble the solid little Dobsonian mount for the lens. In 15 minutes everything seems to be ready and working. Several amateur astronomers from Hong Kong photograph me and my setup. Two Indonesians hunker down and observe everything I do. From the loudspeakers atop the mosque comes the wailing call to prayer.

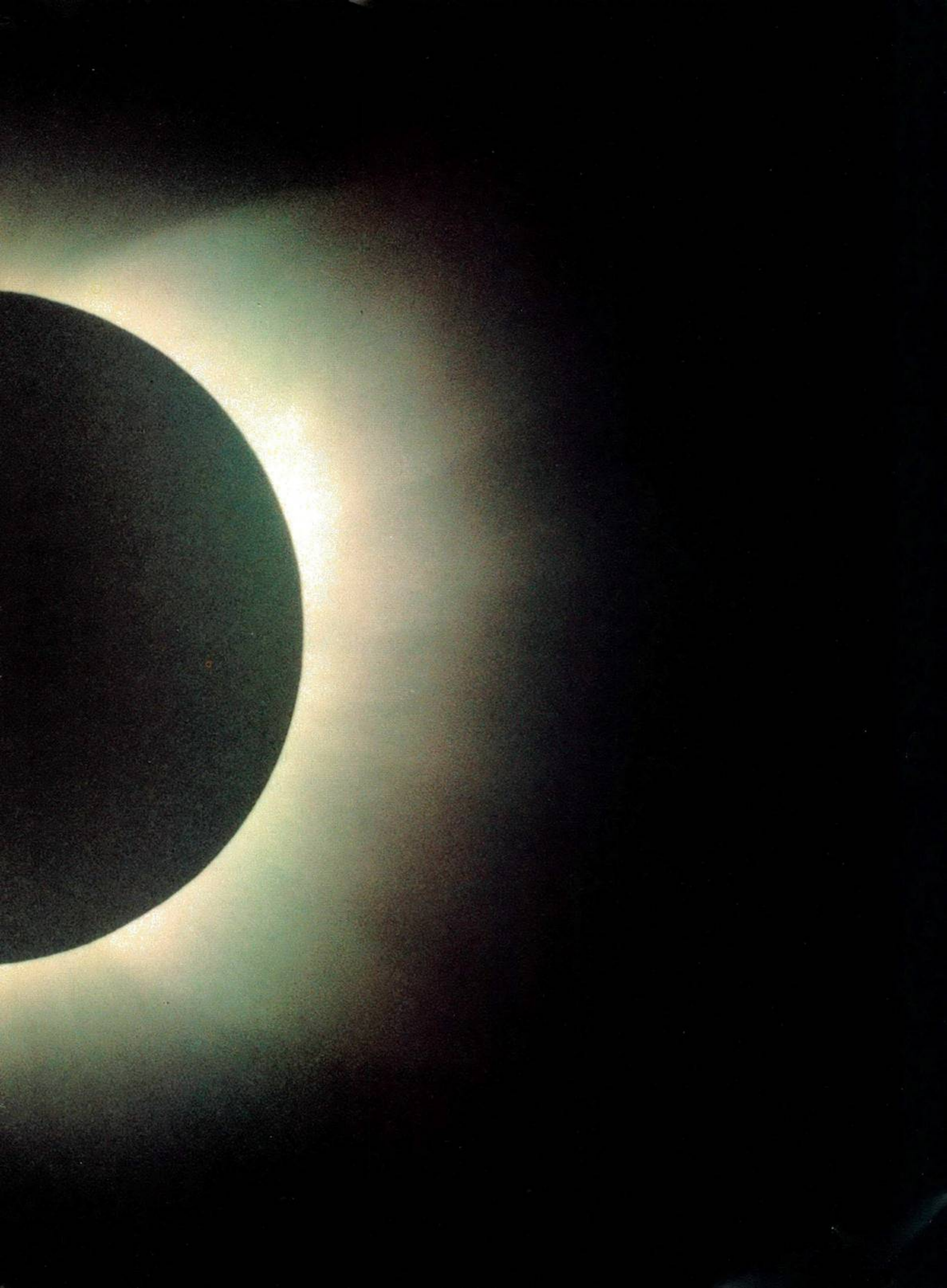
It's 9:58 a.m. — the first nibble's now missing from the Sun. Sweat runs down my face, drips to the ground. I've propped my 4-inch Star-Trap telescope against the camera case and project an image of the Sun on a piece of paper. The soldiers watch, fascinated. Although they are under strict orders not to look at the Sun through filters or the reflection from water, those orders apparently say nothing about looking at a projected image. They're delighted; a loophole — they can watch the eclipse! The lunar bite grows larger; more people join us. Every time the solar image drifts off a bit, the soldiers point to the telescope, and I recenter the Sun.

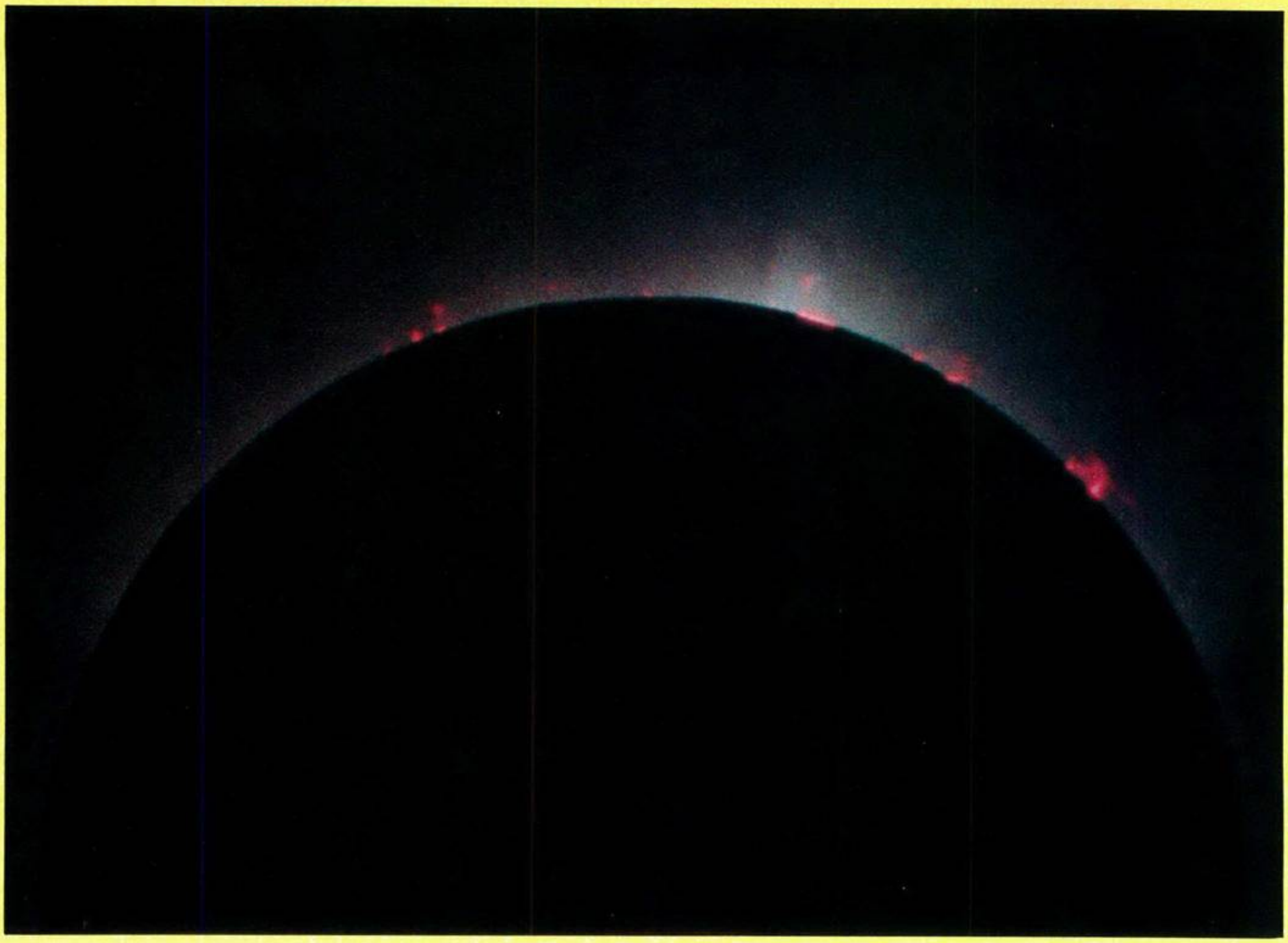
Fifteen minutes before totality, I run the camera through its full range of shutter speeds — they all work — then load it with Vericolor III film, checking twice that it's winding properly. No time remains for mistakes. The Sun is now crescent, shrinking quickly, and the quantity and quality of its light has begun to change noticeably. The temperature is dropping; the air feels still and strange.

We're having a problem with clouds. Dark wisps drift across the solar disk; clouds streak the sky. We spot a large cloud from the east heading straight for the Sun. Five minutes before second contact, then four minutes. It's still coming. 11:29 — three minutes before totality, the cloud reaches the Sun, blotting it out.

I uncap my big lens and glimpse occasional faint flashes of a thinning crescent on the ground glass. I focus carefully on the cloud-dimmed crescent, then fire a frame, in case this is the last we see of the Sun. The cloud keeps moving — there's clear blue behind it. Venus glimmers in the darkening sky now! The cloud thins and the slender, shrinking solar crescent shines again. In the







Previous pages: A ½-second exposure shows middle coronal details. Above: Vivid red prominences and the inner corona recorded just before third contact with an exposure of $^{1}/_{125}$-second. Photos by Richard Berry.

camera's viewfinder, it is painfully brilliant. I look away and fire another frame.

Abruptly the western sky becomes darker than the eastern sky and curiously ruddy. The crescent dwindles to a point of light — a brilliant diamond shining on the ring of coronal light. I trip the shutter twice. The diamond dwindles, the full corona leaps into view. I look a few seconds, then begin my "program": one frame at each shutter speed from $^{1}/_{500}$ down to 1 full second. Check focus; carefully center; then click, wind, change speed; click, wind, change speed — again and again. Every frame counts. I have only 36 exposures. It takes perhaps 60 seconds to run the sequence, but the view through the big lens is sharp and clear. As I watch, the advancing limb of the Moon covers the chromosphere and prominences on the western limb of the Sun.

As soon as the picture sequence is done, I pick up the 4-inch telescope equipped with a 16x Erfle eyepiece and examine the corona. It's far more subtle than photographs ever show it — I can trace delicate streamers extending across the field from the inky black disk of the Moon. I allow myself about 30 seconds of direct viewing, then go back to the camera, which, with lens, magnifies 20 times. Mid-totality is the best time for long exposures of the outer corona. To capture the outer corona, I set the image of the Sun off-center in the frame: high, low, left, right, then a centered five-second exposure.

With that done, I stand up carefully — carefully so I don't fall backward into the fishpond — and look all around me. The horizon is twilight orange, but not very dark. The cloud that gave us such a fright has moved away. Venus shines brightly east of the eclipsed Sun. I can easily see things on the ground. From a clear metallic gray-blue sky, the solar corona shines as bright as a Full Moon, its color hard to describe. "Pearly white" is the closest I come — a white with a strange opalescent quality. The longest coronal streamers extend about two solar diameters.

The sky in the west now begins to brighten — the end is approaching. I squat beside the camera again, recenter the image, begin working through the shutter speeds again: 1, ½, ¼ — hoping to reach $^{1}/_{500}$ just as the diamond ring is ready to reappear. The black disk of the Moon uncovers the eastern limb prominences — click, click, click — the electric pink color of the chromosphere begins to show. Click, click. The chromosphere becomes a broad crescent. $^{1}/_{125}$ — click. $^{1}/_{250}$ — click. $^{1}/_{500}$ — click. Suddenly the tiny spot of the photosphere shines through a lunar valley: click, click — two diamond ring pictures. The blindingly bright photospheric crescent expands — click. Ahhh — the end of the roll — time to point the lens away from the Sun! Five minutes gone so quickly!

After third contact Venus shines in the east for another 10 minutes; the brilliance of Sun builds quickly and the temperature rises. I unload the camera and stow the film safely away, disassemble the mounting, and pack it and the lens back in their box. With fourth contact still an hour away, I suddenly feel very tired, hot, and thirsty.

— Richard Berry

Richard Berry traveled to Indonesia as one of eight educational staff members on one of International Seminar Programs's two Eclipse '83 Expeditions. The Far East tour group included about 80 people, and the itinerary included stays and sightseeing in and around Hong Kong, Bangkok, Singapore, Jakarta, and Bali, as well as the solar eclipse in Tuban.

ASTRONOMY REVIEWS

McGraw-Hill Encyclopedia of Astronomy
Sybil P. Parker, editor
450 pages, hardcover, $44.50
McGraw-Hill (1983)

The dictionary says an encyclopedia is a work that comprehensively treats a particular branch of knowledge, usually through a series of articles arranged alphabetically by subject. The Greek term, *enkyklios paideia*, from which the English word is derived, means "general education." Thus, an encyclopedia of astronomy can be expected to offer a broad overview of all major facets of the science. Moreover, as a practical consideration, the work should have a handy, easy-to-use format.

This pretty well describes the *McGraw-Hill Encyclopedia of Astronomy*. It is a meaty collection of 230 articles on astronomy lifted directly from the 1982 edition of McGraw-Hill's *Encyclopedia of Science and Technology*. The book is heavily slanted toward theoretical and experimental areas, although backyard astronomers interested primarily in observational pursuits will find they have not been totally neglected: 23 major constellations, accompanied by small star charts, have been included.

There are also articles and photographs dealing with the planets, natural satellites, eclipses, well-known star clusters, and individual stars of interest to visual observers. Nonetheless, current technical and theoretical knowledge is the backbone of this collection, and this information is clearly presented in an exacting, authoritative, but unintimidating style.

The book boasts many black and white photographs, as well as 13 color pages; also included is a wide assortment of drawings, charts, and tables. A list of the contributors' names includes J. Allen Hynek, Gerard Kuiper, Bart Bok, Jay Pasachoff, Helen Hogg, Peter van de Kamp, J. Derral Mulholland, and other well-established authorities. The consulting editor is UCLA professor of astronomy George Abell, who also contributed two substantial articles to the volume.

Since the articles have been written by many different authors, an overall inconsistency in style pervades the volume. But this would probably go unnoticed by most readers unless they chose to read one article immediately after another. Major entries begin with a concise topic statement that could stand alone as a succinct definition. Next, depending on the depth to which the article goes, additional material is offered in a cogent article. Longer entries have been broken into major categories or headings.

For example, in the article "Galaxy, External" the opening sentence is, "One of the large, self-gravitating aggregates of stars, gas and dust which contain nearly all of the observed matter in the universe." Then in the next seven pages, Joseph Silk, professor of astronomy at Berkeley and author of *The Big Bang*, elaborates on his opening statement, exploring the major areas pertinent to external galaxies, such as composition, form and size, internal motions, luminosities, clustering, masses, interactions, nuclei, distances, cosmology, and evolution. Each area is a tersely written, fact-filled essay that describes the major topic. The result is an explanation that synthesizes what is known about galaxies other than our own Milky Way. The article is laced with references that point to other related topics in the volume, and four photographs enhance the text matter. The article concludes with a seven-item bibliography. Finally, like all the other articles, it is signed.

Of course, since this is a one-volume treatment, arguments can be made that this or that topic should have received greater coverage; indeed, no encyclopedia ever escapes this sort of criticism. Nevertheless, within its space limitations, the work has much to offer. Above all, it is not a dull storehouse of stuffy, dust-dry information. In fact, it satisfies what may be the best test of any encyclopedia — how hard it is to *stop* looking stuff up in it. In a good work, all sorts of interesting entries — each begging to be read — seem to pop out at you every time you open it.

Anyone interested in astronomy who has need of an authoritative and comprehensive (albeit pricey) single-volume reference would do well to consider this work. *Gail O. Clark*.

Astronomy & Telescopes: A Beginner's Handbook
Robert J. Traister and Susan E. Harris
192 pages, hardcover, $19.95; paperback, $14.95
Tab Books, Inc. (1983)

This book was produced by a company that specializes in publishing technical manuals for computers, automobiles, telephones, guns, and airplanes. In at least this case, the company has produced a quick, haphazard book. The bulk of this work is obviously rewritten material from commercial telescope manufacturers' owner's manuals. The coverage is sloppy, and abounds with poorly-written, uncritical material that doesn't come close to what a beginner should know. The authors give the impression that they're confused about their subject matter; qualifying words appear everywhere, as if to say, "this is basically what it means, but we're not sure, so we're generalizing."

Example: on page 66 the authors state that Cepheid variable stars fluctuate in brightness in a "somewhat consistent manner." Cepheids are extremely regular variable stars. On page 68, writing about the distribution of globular clusters, they state that globulars are "usually located near what is considered to be the center of our Galaxy." I can't think of a more hesitant way to construct that sentence. Besides — globulars orbit the center of the Galaxy, but are distributed all over the sky. The authors make many more erroneous or misleading statements, including, "there are 88 constellations, at the time of this writing," as if they expected to see an 89th appear before the book was printed.

It would indeed be sad to watch a rank beginner trying to grind a mirror from the instructions included in this tome. On page 126, a mere third of a page is devoted to testing mirrors. The idea that a beginner could successfully test a mirror based on this scant information is ludicrous!

Blatant advertising crops up everywhere — including current prices for telescopes and telescope parts. After reading a page of this stuff, you get the impression that you're expected to rush out and buy one of the telescopes sold by the guys who obviously provided most of the material — including the photos — that appears in this book. Clearly this book cannot be recommended to anyone. If you want commercial literature, contact the telescope manufacturers. They'll provide you with a handful for a lot less than $20. *David J. Eicher.*

Aurora Borealis: The Amazing Northern Lights
S.-I. Akasofu
95 pages, paperback, $7.95
Alaska Geographic (1979)

Alaska Geographic is a quarterly publication that tackles a variety of topics "on the lands north of 51°16'." An issue on the northern lights was a natural. Although this book is labeled "Volume 6, No. 2" and seems to be a back issue of the periodical, it's an attractive and interesting product.

With the exception of two reprinted articles, the text was written by University of Alaska geophysicist S.-I. Akasofu, who first recognized the existence of an oval of aurora fixed over Earth's magnetic pole. Akasofu covers auroral legends, polar explorers, and settlers of the north in the first three sections, which are liberally illustrated with fine color photographs and old engravings. The rest of the book concentrates on understanding the aurora. While considerably oversimplified, Akasofu's descripton of the magnetosphere and its interaction with solar particles is accurate enough for most lay readers.

As a whole, the book's strength lies in the history it presents and not in its description of scientific connections between the solar wind, the terrestrial magnetic field, and the aurora. Given that, it's a fine book at an affordable price. *Francis Reddy.*

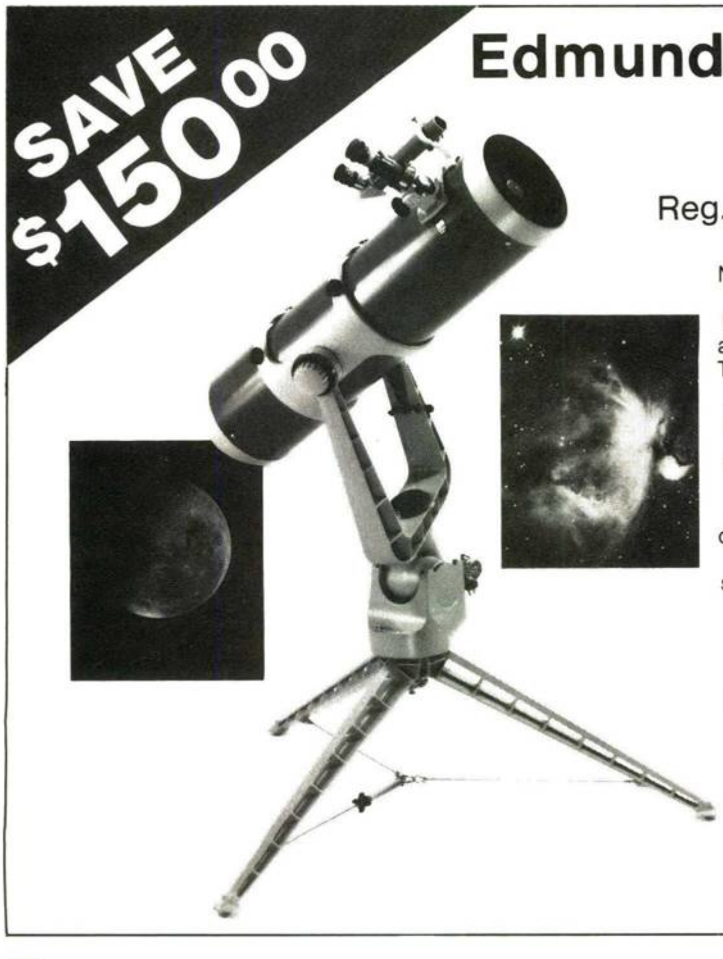
Proceedings of AstroCon '81
Gary A. Becker, ed.
174 pages, paperback, $8
Astronomical League (1983)
[publisher's address: C. Chambliss, Kutztown State College, Kutztown, PA 19530]

This proceedings volume is composed of papers given at the Astronomical League's national convention held at Kutztown, Pennsylvania, in 1981. Just now published by the League, the book contains some interesting transcripts: Frank Drake speaking on the possibility of extraterrestrial life, George Abell on astronomical fallacies, William Brunk on the Voyager missions, and Harry Shipman on black holes.

The amateur papers and workshops cover a variety of topics, including telescope making, planetary observing, photoelectric photometry, astrophotography, and computing in astronomy. There are the usual photos of convention-goers standing around, listening to talks, visiting nearby observatories, etc., but they are put together in a non-abrasive manner. The book makes a fine contribution to the understanding of what amateur astronomers are thinking about these days, the exclusion of deep-sky material notwithstanding. *David J. Eicher.*

Planetary Nebulae
D.R. Flower, ed.
557 pages, hardcover, $65; paperback, $30.50
Reidel (1983)

Planetary nebulae are the glowing spherical shells of gas surrounding certain types of stars. Astronomers think that most stars eject substantial amounts of matter in the course of normal stellar evolution,



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but no one yet knows the mechanisms that eject these shells and set them aglow. Are they sloughed off in minor stellar outbursts, or are they simply gas shocked into fluorescence by an energetic stellar wind?

This volume contains the proceedings of the International Astronomical Union's session on planetary nebulae, held at University College London in August 1982. Topics include observations of planetary nebulae, relevant physical processes, determinations of chemical abundance, mass loss mechanisms, and evolution of the central stars.

The Fascinating Universe
Werner Buedeler
252 pages, hardcover, $25.50
Van Nostrand Reinhold (1983)

Translated from a German book published in 1981, *The Fascinating Universe* tells the story of the development of astronomy since about the turn of the century, with special emphasis on the past few decades. The author is a West German TV personality, and the book was written to accompany his show.

Exploring the Cosmos
Louis Berman and J.C. Evans
543 pages, paperback, $25.95
Little, Brown (1983)

Now in its fourth edition, this book is a text intended for one or two semester courses in astronomy for non-science majors.

Pocket Computer Programs for Astronomers
Fred Klein
100 pages, paperback, $12.95
Klein Publications (1983)
[address: 12225 Magdalena,
Los Altos, CA 94022]

This book provides 13 BASIC programs (for Sharp PC-1211 and TRS-80 pocket computers) that calculate altitude and azimuth, asteroid positions from orbital elements, sidereal time, positions of the main jovian and saturnian satellites, age and phase of the Moon for a given date, and other information.

Beachheads in Space
Jerry Grey
274 pages, hardcover, $14.95
Macmillan (1983)

What to do next in space is the topic addressed in this book, which recommends that a strong national effort be made to use space in every way possible — including space stations, advanced Shuttles, and the like.

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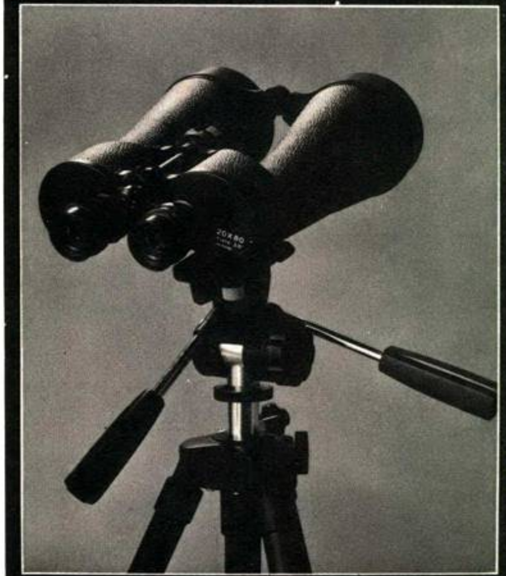

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Wm. Hartmann photo

eye on the sky

an eventful month for skywatchers

by Fred Schaaf

the wanderers

This month is filled with exciting celestial events: Jupiter undergoes conjunctions with Beta Scorpii and Uranus, Venus leaps into the pre-dawn sky, Mars passes less than a degree from Regulus, Mercury puts in its best morning appearance, and North American viewers can witness a very young Moon.

In the evening skies, **Saturn** is the only naked-eye planet that is not especially interesting this month. It will be difficult to see by month's end, low in the southwest as night falls.

Jupiter, on the other hand, is still almost 70° from the Sun as autumn starts, and undergoes several important conjunctions. During September it hangs high in the northwestern section of Scorpius, cutting between Beta (β) and Omega (ω) Scorpii. Thus this year's final conjunction between Jupiter and Beta Scorpii isn't as close as the first two. But on September 3, look for the bright gas giant less than one-half degree south of third-magnitude Beta.

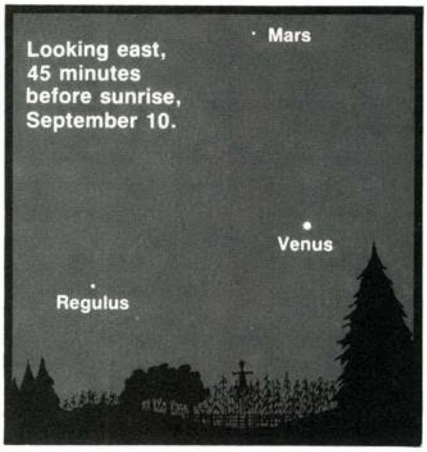
On the 12th the Moon occults Jupiter, but only from the point of view of Europeans, Africans, and northern Canadians. Most North Americans will see Jupiter just under a degree away from the lunar limb. But another close approach will be visible all over the globe: on September 24, Jupiter passes just 27′ north of **Uranus**. The little sixth-magnitude pale green disk will be overwhelmed by Jupiter's glare, but binoculars or low-power telescopes will show the two quite well.

The opportunity is a rare one. The next Jupiter-Uranus conjunction will occur on February 16, 1997. On that date, their separation will be just 10′, but their elongation from the Sun will be only 22°. The 1997 conjunction will be part of a marvelous multi-planet gathering in the pre-dawn sky. Another pre-dawn congregation of many planets is due next January.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

While we enjoy this month's Jupiter conjunctions (and prepare for more next month), **Venus** ascends into the morning sky, rapidly brightening and increasing its angular separation from the Sun. On September 1, the brilliant morning star rises just half an hour before the Sun; at the end of the month, however, it precedes Sol by three hours.

The gain is not as great as it could be, because Venus is farthest south of the ecliptic plane just days after it was closest to us in late August. From a distance of less than 30 million miles, Venus's farthest dip below the plane of the Earth's orbit seems quite a plunge, placing the planet way down in Hydra. In fact, around mid-month, we can look for the unusual sight of Venus in the vicinity of the head of Hydra.



Is that far south of the ecliptic? Consider the following: on the morning of the 14th, Venus is in conjunction with **Mars** but is a full 8½° south of the second-magnitude Red Planet. A far more interesting conjunction occurs when Mars lies only a degree from Regulus on the mornings of the 28th and 29th, at 36° elongation from the Sun. But a more remarkable indication of Venus' southern trip happens on the morning of September 5, when Venus is located 13° south of the Moon.

Venus should be easily visible after sunrise by month's end, when it shines at magnitude -4.2. If you look at it in the sky just after sunrise for about a week after September 6th, you just might achieve a truly phenomenal observation. Venus now shows a large, thin crescent, easily visible in telescopes. But is it possible to glimpse the crescent of Venus without optical aid? Such claims are always controversial — and often questionable. If you have sharp eyes, go out and decide for yourself.

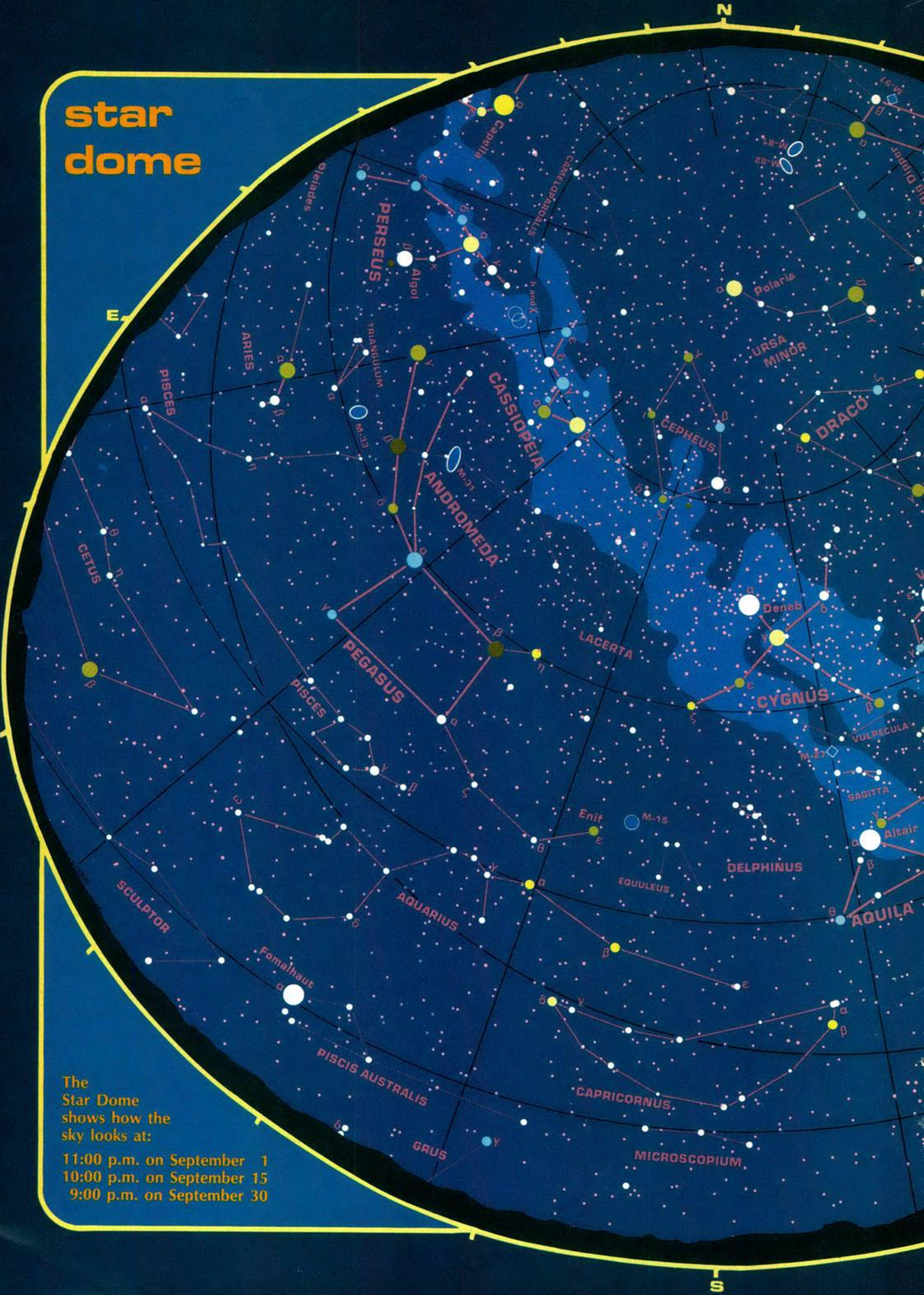
The other inner planet, **Mercury**, is at inferior conjunction on September 15 (after being farthest south of the ecliptic plane on the 7th, just four days after Venus). By the end of the month it swings upward, starting its best morning apparition of the year. It will be at greatest eastern elongation on the first of October.

Finally, a rare sight might be visible on the morning of September 6 — a very old, thin Moon. On the East Coast of the United States the Moon will be just 16½ hours before New a little while before sunrise; on the West Coast, it will be a record-breaking 13½ hours.

Is there a chance of perceiving such a slender crescent? Hope for excellent sky conditions and look very low in the east, starting about 30 minutes before sunrise. It will be difficult even in the best of conditions, but all the astronomical factors will be extremely favorable: the ecliptic here is nearly at its steepest, the Moon is well north of the ecliptic, and last but not least, the Moon is only about four hours past perigee.

On May 11, Henry Nebel photographed Comet IRAS-Araki-Alcock and the Beehive Cluster beside one of the domes at Alfred University Observatory. He used a 50mm f/2.0 lens, 400 ASA film pushed to 800 ASA, and a 5-minute exposure.

star dome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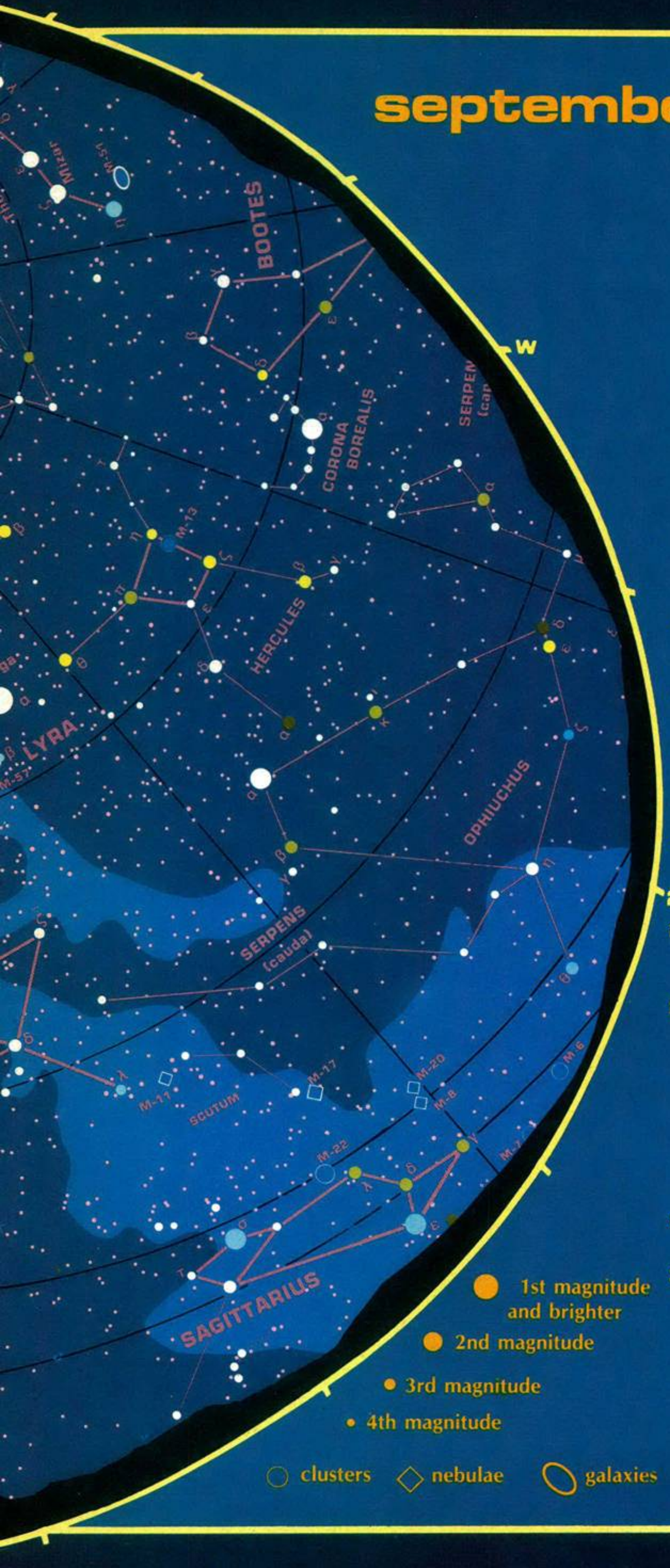
SCULPTOR
AQUARIUS
AQUILA
Fomalhaut
PISCIS AUSTRALIS
CAPRICORNUS
GRUS
MICROSCOPIUM

The
Star Dome
shows how the
sky looks at:

11:00 p.m. on September 1
10:00 p.m. on September 15
9:00 p.m. on September 30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M-22
M-7
SAGITTARIUS
1st magnitude and brighter
2nd magnitude
3rd magnitude
4th magnitude
clusters
nebulae
galaxies

september sky almanac

3rd	Jupiter will pass 26′ of arc (just less than one Moon-diameter) south of the star Beta (β) Scorpii's brighter component at 5:34 p.m. EDT. By the time it becomes dark, the planet will already be slightly to the east of the star. Use unaided vision or binoculars to observe.
5th	The Moon will lie between Mars and Venus this morning. Look east in the hour before sunrise.
6th	The Moon is at perigee at 1:10 a.m. EDT: 222,754 miles. Later today the Moon is New (10:35 p.m. EDT).
10th	This evening the Moon will overtake Saturn, missing it as it passes 1.7° to the north of the planet.
12th	Tonight it's Jupiter's turn: the Moon will pass a degree north of it.
13th	First Quarter Moon occurs at 10:24 p.m. EDT.
15th	Mercury is at inferior conjunction
18th	The Moon is at apogee at 12:44 p.m. EDT: 252,071 miles.
22nd	The Moon is Full at 2:36 a.m. EDT.
23rd	Fall begins at 10:42 a.m. EDT as the Sun crosses the celestial equator from north to south.
24th	Jupiter will pass 0.4° north of Uranus at 5:31 p.m. EDT. As with the Beta Scorpii event on the 3rd, you'll have to observe them a little later, after sunset. Uranus will be very difficult to make out next to gleaming Jupiter unless you use binoculars or a telescope.
29th	Last Quarter Moon is at 4:05 p.m. EDT.
30th	Mercury passes through perihelion.

Jupiter now rides high in the head of Scorpius, undergoing several conjunctions this month. Back in May, Ron Gattie photographed it using a 50mm f/2.8 lens, 400 ASA film, and a 1-minute exposure.

the starry sky

Early autumn is a time of crisp, steady skies and cool, comfortable temperatures. The dominant grouping of stars at this time of year — hovering directly overhead in the evening — is **Cygnus** the Swan.

A neighbor of this large, bright cross-shaped configuration is **Vega** and its constellation, **Lyra** the Lyre. The brightest star in Cygnus is more than two and a half times dimmer than Vega, but still shines at first magnitude. It is **Deneb**, which forms the Summer Triangle with Vega and the more southerly **Altair** in **Aquila** the Eagle.

The body of the Swan is composed of a line of stars from Deneb (the tail) to much fainter double star **Albireo** (the eye). The line of the wings is perpendicular to the body and also to the band of the Milky Way, which is very bright in Cygnus. This main pattern is also known as the Northern Cross.

How dark are your skies at night? Even if your viewing is disturbed by city lights or a bright Moon, you still may be able to discern the Cygnus Star Cloud, located near the center of the cross. If your skies are quite good, you should be able to detect the **North America Nebula** near Deneb. The geographical center of continental North America is in North Dakota — and the North America Nebula lies centered above it on September evenings.

Cygnus can be a guide to locating several tiny but interesting constellations in and around the Summer Triangle. A faint zigzag of stars south of the Swan's neck and head is **Vulpecula** the Fox. Last Memorial Day weekend an unusual event happened here: asteroid **Pallas** occulted the star **1 Vulpeculae**. Also in the constellation is the **Dumbbell Nebula**, a bright planetary nebula visible in binoculars under good conditions. It lies near the point of **Sagitta** the Arrow, a small, dim grouping of stars.

If you can spot Sagitta you can probably easily see ***Delphinus*** *the Dolphin*. Delphinus is not brighter than Sagitta, so why should you see it more easily? The trick is that Sagitta is immersed in bright

Milky Way stars, while Delphinus lies just outside the luminous band.

The Swan's course of flight down the Milky Way aims it roughly toward the apparent position of the Center of the Galaxy in Sagittarius. The pattern of **Sagittarius** itself is now low in the southwest. If you extend the line from Albireo to Deneb in the other direction, you'll move northeast toward the bright pattern of **Cassiopeia** the Queen. Later in the evening she'll be higher in the sky, but right now her larger, dimmer husband is approaching his upper culminaton.

The outline of **Cepheus** the King resembles a little upside-down church whose steeple is represented by the star **Errai**, Gamma (γ) Cephei. Some of the stars of Cepheus in the Milky Way band include those of the church's "foundation": **Alderamin**, Alpha (α) Cephei, the brightest star in the constellation; **Delta** (δ) **Cephei**, a famous naked-eye variable star; and **Mu** (μ) **Cephei**, a red giant whose color spawned the nickname, Herschel's Garnet Star.

What about the line of the Swan's wings? Extending it to the northwest — a little more than one full wingspan — leads to the head of **Draco** the Dragon. Extending it almost two wingspans southeastward takes you roughly to **Enif**, the second-magnitude fiery nose of **Pegasus** the Winged Horse. Pegasus' nose lies far from his body, which is represented by the Great Square of Pegasus, now prominent in the east.

Stand facing due south and you can travel from Cygnus straight down the meridian to Delphinus and finally to the isolated form of **Capricornus** the Sea-Goat. This ancient constellation is tipped on the west end with **Beta** (β) **Capricorni** and the tricky naked-eye double **Alpha** (α) **Capricorni**.

When Deneb is near the zenith, other first-magnitude stars occupy three corners of the sky. **Arcturus** is setting in the northwest, **Capella** is rising in the northeast, and **Fomalhaut** is low in the southeast. Can you see Arcturus and Capella — two similarly bright stars — at the same time from your latitude?

skylore

The name Orion is well-known to all sky observers, but the mythological name Arion is less renowned. Arion is the poet whose tale is usually connected with the constellation Delphinus. Apparently a real person who lived and wrote around 700 B.C., he lived in the court of another historical figure — Periander, the ruler of Corinth. Arion is credited with inventing the *dithyramb* verse form, in honor of the god Dionysus. A fragment of a poem attributed to Arion — *Hymn to Poseidon* — has survived. But the real man became colored with legend, and now, as often happens, we remember him chiefly because of the myth to which he became attached.

According to the tale, Arion of Lesbos was a son of Poseidon and the nymph Oneaea. He was a master of the lyre and therefore sometimes has been associated with Lyra, although that constellation is more often connected with the most famous of ancient legendary musicians, Orpheus. Arion's chief feat of minstrelsy rivals even those of Orpheus.

Arion had taken leave of Corinth and his patron Periander to perform in Sicily. There, some say, he won a competition and was heaped with riches in reward for his great musical talents. Unfortunately, this wealth incited the greed of the captain and crew that Periander had commissioned for Arion's journey. These sailors agreed to a plan to rob the poet of not only his riches, but his life.

When the ship was far out to sea on its return to Corinth, Arion learned that his fate was to be a watery grave. He tried to persuade the sailors from their evil plan, but even his most compelling songs had no effect on their ruthless hearts. Death seemed certain; all they would permit him was one last song.

The sailors did not know that this song attracted a school of dolphins, the traditional friends of the shipwrecked and drowning. After the ship had left Arion far behind in the sea, one of the dolphins came to Arion's aid. The dolphin saved Arion from sinking and carried him on its back homeward across the waters.

When the treacherous sailors reached Corinth, they explained to Periander that Arion had enjoyed Sicily so much he had refused to return with them. But even as they swore to the truth of their claim, a figure suddenly appeared from behind Periander. It was Arion. We can imagine the greedy sailors' astonishment. Their punishment was immediate execution. But the noble dolphin, who had easily outpaced the ship to Corinth, had his image set among the stars as Delphinus.

The ancient Greeks greatly revered dolphins and told many stories about their rescues of the shipwrecked. Delphinus is thus also associated with dolphins who saved the lovers Enalus and Phineis, the Italy-bound Philanthus, and Taras, the founder of Tarentum. Delphinus could also be the dolphin form of Apollo when this god guided Icadius of Crete to a haven that became the site of the most famous oracle of all time — the oracle of Delphi, named for the dolphin.

Still other Greek stories celebrate the dolphin. Delphinus might be the dolphin who persuaded the nymph Amphitrite to become the wife of Poseidon and thus queen of the sea. One of the first great Greek writers was Hesiod, who probably lived at least a century before Arion and was supposedly killed by assassins and cast into the sea. But dolphins returned the body to shore, where friends found it. Aided by Hesiod's dogs, they tracked down the killers. The murderers drowned in the very waters into which they had flung Hesiod.

The original Delphinus may have been much larger, including stars we now place in its dim neighbor Equuleus, but our current constellation does have the outline of a fish-like creature. Nevertheless, Al Biruni gave the early Arab title as Al Kaud, the Riding Camel (presumably the Arabs were somewhat more familiar with camels than dolphins) and reported that several early Christian sects thought Delphinus was the Cross of Jesus raised to the sky after the crucifixion. Other names have been given to these stars, perhaps the most mysterious being "Job's Coffin."

Today we know that the Greeks were justified in their great respect for the dolphin. The dolphin's brain is complex. Its hearing, the most developed sense, is greatly superior to ours. We must wonder whether or not these dolphins have similarly named some small pattern of stars Homo the Human — in the clicks and whistles of dolphin language, of course.

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ANNOUNCEMENT — Amateur astronomy class, including how to select and use a telescope, observing hints, astrophotography, and basic astronomy. Locate planets, constellations, deep-sky objects with naked eye, binoculars, telescopes. Star party field trips. Registration begins September 15. Contact Pierce College Community Services, Woodland Hills, CA. Phone (213) 884-4455.

ANNOUNCEMENT — The Amateur Astronomers Association of Princeton will present slide shows, telescopes, and astronomy exhibits at the Community Booth, main level, Quaker Bridge Mall on Rt. 1 in Lawrenceville, New Jersey, on September 24th and 25th.

ANNOUNCEMENT — A new amateur astronomy club is being formed in the Norman, Oklahoma, area. Beginners and experienced amateurs are all welcome. Contact Jim Cypser, 707 DeBarr Ave., #2, Norman, OK 73069.

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ANNOUNCEMENT — The Plutonian Society is looking for anyone who wishes to participate in a Halley Watch Program and information on Halley's return. Contact Brian Stuhr, 810 N.E. 5th St., Marion, WI 54950.

WANTED — Assistant producer, Davis Planetarium. Duties include photography, audio production, writing, and presenting live astronomy programs. Bachelor's degree required. Previous planetarium experience preferred. Closing date September 16, 1983. Send letters and resume to Mrs. Lee Sattler, Maryland Science Center, Baltimore, MD 21230.

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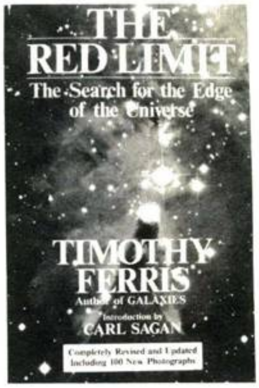
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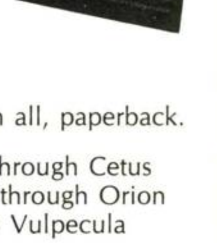

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photography
in
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by
Hal Jandorf

Aperture fever — what does it mean to you? Budding astrophotographers often become overwhelmed by the spectacular, seemingly flawless, unmatchably detailed color deep-sky photos taken with large-aperture instruments. Professional astronomers are no longer the only ones capable of awesome color astrophotography. Why should you go out and take pictures of M-42 with your 4-inch reflector if other guys are producing supercooled, hypered, tri-color plates made with 20-inch telescopes? So you sit inside, fearful of this new breed of astrophoto superstar, tearfully paging through the latest issue of ASTRONOMY.

Come on now, it's not all that bad. Sometimes all those spectacular color photographs taken with expensive, large-aperture telescopes may lead you to overlook the photographic potential of your small reflecting telescope. But you've got advantages you may not have considered.

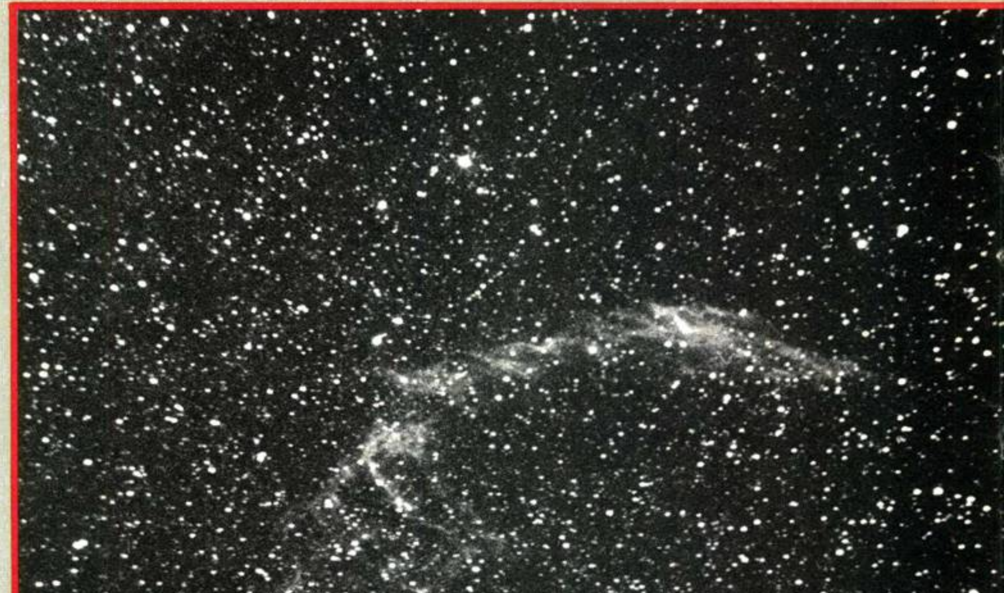
To make the photographs shown in this article, I used a 4¼-inch f/4.7 reflector — a rich-field telescope (RFT). If you have such a telescope, read on. If you don't and want to produce beautiful astrophotos without exhausting efforts, you can buy one or purchase the mirror and components separately and put them together yourself very easily.

Pros and Cons

Why should you use a small RFT for photography? One good reason is the amount of sky coverage you'll get. A 4¼-inch f/5 reflector has a focal length of about 20 inches (or some 500 millimeters), and will cover a large area of the sky without sacrificing details (see box on page 54). You'll achieve more resolution than you would using an ordinary telephoto lens, thereby recording more detail in nebulae, galaxies, and star clusters. Large objects like the Rosette or California Nebulae and open star clusters like the Double Cluster in Perseus are ideal targets for small RFTs. These scopes are also great for photographing comets and other wide-field phenomena.

Another strong reason for making sky pictures with a small RFT is its fast photographic speed. Working at f/4 or f/5, you can record deep-sky objects in exposures of only 5 to 20 minutes. This enables you to take more photographs in a night, reduces fatigue from guiding long exposures, and minimizes tracking errors.

An RFT's ease of portability makes it a pleasure to transport, set up, and use. The entire system fits into the trunk of a subcompact car; try *that* with a 12½-inch photographic telescope! And you don't have to be a *sumo* wrestler to lift the entire 4-inch RFT and move it to a better location.



Above: The Veil Nebula in Cygnus is a huge, although faint, supernova remnant; the easternmost part of the loop is NGC-6992-5, visible as a ghostly arc of faint nebulosity. This is a 45-minute exposure on 103aE emulsion. Right: M-42 in Orion is the brightest emission nebula in the Northern Hemisphere. The yellow and orange hues represent hot ionized gas, while the subtle bluish nebulosity shines by reflected starlight. This is a 15-minute exposure on Ektachrome 200. All photos in this article are by the author and were made with a 4¼-inch f/4.7 RFT.

There are, of course, some limitations to a little RFT. Small nebulae, galaxies and globular clusters are best recorded using larger, longer focal length telescopes. Lunar and planetary photography is also better left to longer focal length instruments. Larger telescopes have larger image scales: they isolate details in deep-sky objects that are out of reach for smaller instruments.

But for wide-field coverage of deep-sky subjects, a small RFT is unsurpassed. Remember that you can also use your RFT to observe: plop in a wide-field eyepiece to view the Milky Way, a loose open cluster, or a new comet, and you'll find that the small reflector is just as enjoyable for visual observing.

The Telescope

The main photographic instrument, the RFT, is the heart of the system. In assembling such an instrument from scratch — or upgrading the telescope you already own — you should consider certain materials. Aluminum tubing is a good choice: its high rigidity supports the weight of cameras and guidescopes with little flexure. And since the telescope tube is short and stubby — probably less than five inches in diameter — the tube's cost will be low.

The focuser should couple the camera to the telescope with a very short distance between tube surface and film plane, minimizing flexure and balance problems. It can be either a helical or rack-and-pinion type and should have a set screw to lock in the sharpest possible focus. A 2-inch diameter focuser will increase the light available to the edges of the film frame and is a necessity if you decide to use a large diagonal mirror. Bear in mind that using a low-profile focuser may require an extension tube to allow eyepieces to reach focus for visual observing. However, you'll want to put up with this minor inconvenience long before you take the step of moving the primary mirror up to achieve focus — a necessity with a standard "tall" focuser. A camera teetering six inches out from the tube creates all sorts of flexure and balance problems, not to mention the risk of the camera falling off the telescope.

Flexure: the Photographic Gremlin

Movement of the guidescope relative to the camera — flexure — is intolerable. The primary and secondary mirrors should be secured in their cells with three dabs of silicone adhesive. You should lock the mirror in place with screws and tighten the secondary so it can't move. Three or four vane spiders work best for rigidly holding the secondary in place. The bolts should be tightened to provide equal tension on each vane.

As a quick test for flexure, shake the telescope tube assembly. If anything rattles or clunks, find it and secure it. A more accurate test is to place a crosshair eyepiece in both telescope and guidescope. Using Barlow lenses, center a bright star in each scope. Track a star with both telescopes for about an hour, then center the star in the guidescope, using the equatorial mount's slow motion controls. If the star is not still centered in the photographic telescope, something has moved. Check the telescope, guidescope, and guidescope mounting rings for looseness until the problem is fixed.

Secondary Mirror Size

The size of the secondary mirror is important (see box on page 54). It has to be large enough to provide good illumination across the 35mm film frame, yet small

Hundreds of white, bluish-white, and yellowish stars illuminate the field of the Double Cluster in Perseus. The exposure lasted 15 minutes on hypersensitized Kodacolor 400 film.

selected objects for RFT photography

Object	Con	Suggested Exposure Time
M-6, Butterfly Cluster	Sco	15 minutes
M-7, open cluster	Sco	15
M-35, open cluster	Gem	15
M-41, open cluster	CMa	15
M-44, Beehive Cluster	Cnc	15
M-46/M-47, open clusters	Pup	15
M-8/M-20, Lagoon and Trifid Nebulae	Sgr	20
M-16/M-17, Eagle and Omega Nebulae	Ser/Sgr	20
M-42, Orion Nebula	Ori	20
M-45, Pleiades	Tau	20
NGC-869/884, Double Cluster	Per	20
M-31, Andromeda Galaxy	And	30
M-33, galaxy	Tri	30
NGC-2237/9, Rosette Nebula	Mon	30
NGC-7293, Helical Nebula	Aqr	30
NGC-1499, California Nebula	Per	45
NGC-6960/6992-5, Veil Nebula	Cyg	45
NGC-7000, North America Nebula	Cyg	45
B-33, Horsehead Nebula	Ori	45

enough not to block too much light from reaching the primary mirror. These two factors usually result in a compromise. Although a photographic RFT should have a large secondary mirror, this can reduce image quality and contrast for visual observing. But a small secondary will introduce light fall-off (vignetting) at the edge of the frame. You can choose a mirror between the visual and photographic values and still produce fine photos.

The Guidescope

The guide telescope can be simple. It doesn't have to be more than that old neglected 60mm refractor you have lying around in your garage. (You can easily pick up one of these at a swap meet or garage sale.) Add a Barlow lens and guiding eyepiece, and you're all set. Of course, the guidescope has to be rigid: this may mean adding another set screw or shimming with electrical tape to take up play in the focuser. As a rule of thumb, you should guide your telescope with a magnifying power of about four to five times the focal length (in inches) of the photographic telescope. This means that if the focal length of your RFT is 25 inches, you should guide at 100x to 125x, an easy

Left: The Horsehead Nebula in Orion is a fine example of a dark nebula — a vast cloud of interstellar dust grains. The reddish streamer is an emission nebula: the dark cloud silhouetted against it lies much closer to us. This is a 30-minute exposure on hypersensitized Ektachrome 200. Above: M-35 is a large open star cluster in Gemini. The fainter cluster on its edge is probably similar in structure, but lies over six times farther away. The exposure lasted 15 minutes on hypersensitized Kodacolor 400.

M-31 in Andromeda is far and away the finest observable example of a galaxy in the sky. This is a 30-minute exposure on hypersensitized Ektachrome 200.

range of magnification for a small refractor.

The Mounting

The telescope's mounting should be a sturdy equatorial with an accurate clock drive. A declination slow motion control — manual or electric — is also a necessity. Although most of the light-duty, commercial mounts do a poor job of supporting the 8-inch reflectors they were supplied with, they will easily support a 4-inch to 6-inch RFT.

The drive should be free from play, binding, and backlash. The clutch must be tightened to avoid slippage during exposures. A typical mount's pedestal can use some beefing up. Steel cables with turnbuckles attached to the pedestal legs and at the top of the pier will add to your mount's stability.

Once the mount is in good shape, you'll have to aim it correctly. Polar alignment is very important for almost all deep-sky astrophotography: you should spend some time carefully getting it right. (See "Easy Steps to Perfect Polar Alignment," ASTRONOMY, August 1982.)

Focusing and Films

Focusing is critical, since a short focal length telescope has a small depth of focus and doesn't allow much room for error. Take time to get the smallest star image possible on your focusing screen. If you have interchangeable screens on your SLR, use one with a fine matte finish. Clear focusing screens are adequate for long-focus lunar and planetary photography, but with short-focus RFTs they allow the eye to focus independently on a star field, which can result in an out-of-focus image. A matte screen allows you to focus on stars by their size. Try to focus on a bright star near the object you are photographing, then shift to your subject. You can orient the object in the camera's field of view by rotating the camera in the focuser. Once your subject is properly framed, clamp the focuser locking screws, and you're ready to find a guide star.

Start searching for a reasonably bright guide star with the guide telescope at low power; you may have to decenter the photographic subject to get a suitable star in the guidescope. Once you've found a star, carefully clamp the guidescope locking screws and exchange your low-power eyepiece for the illuminated reticle eyepiece and a Barlow lens. Center the

a checklist for astrophotography

You'll need the following items to do deep-sky astrophotography with a small telescope. Make sure that you set up everything and test it before actually exposing film: this will save you from Murphy's Law — if anything can go wrong, it will — which seems to prey on astrophotographers. If all is in good working order, you need only polar align, compose your subject, focus, and shoot!

☐ Telescope
☐ Guidescope
☐ Barlow lens
☐ Illuminated reticle ocular
☐ Equatorial mount and clock drive
☐ Drive corrector and slow motions
☐ 35mm SLR camera
☐ Timer with bell
☐ Self-locking cable release
☐ Chair for guiding
☐ List of photographic targets
☐ Film

RFT data

sky coverage

aperture	f/ratio:	f/4	f/5	f/6
4¼-inch		4.8° x 3.2°	3.8° x 2.5°	3.2° x 2.1°
6-inch		3.4° x 2.3°	2.7° x 1.8°	2.3° x 1.5°

secondary mirror size (minor axes)

(visual sizes are given in parentheses)

aperture	f/ratio:	f/4	f/5	f/6
4¼-inch		2.30″ (1.83″)	2.00″ (1.50″)	1.83″ (1.25″)
6-inch		2.60″ (2.14″)	2.40″ (1.83″)	2.00″ (1.50″)

star on the crosshair, using your drive corrector's slow motions and the declination slow motion control. Orient the crosshair eyepiece so that the crosshairs parallel the motions of right ascension and declination (you can do this by turning the eyepiece). Become familiar with the slow motion correction directions before you start your exposure. It's a good idea to practice guiding for a few minutes before you open your shutter.

Use a self-locking cable release; this enables you to open the shutter with one hand while the other remains free for tracking corrections. A kitchen timer serves well to time your exposures.

For black and white photography, the best films to use are the 103a series spectroscopic films or hypered Technical Pan 2415. You can get good color results by using Ektachrome 400 or Fujichrome 400, especially if they are hypersensitized. If you want to make color negatives, try Kodak's VR-1000 film. You'll probably need to expose from 10 minutes for bright clusters to 45 minutes for faint nebulae like the Horsehead in Orion (see box on page 52), but you'll get useable pictures in shorter five-minute exposures.

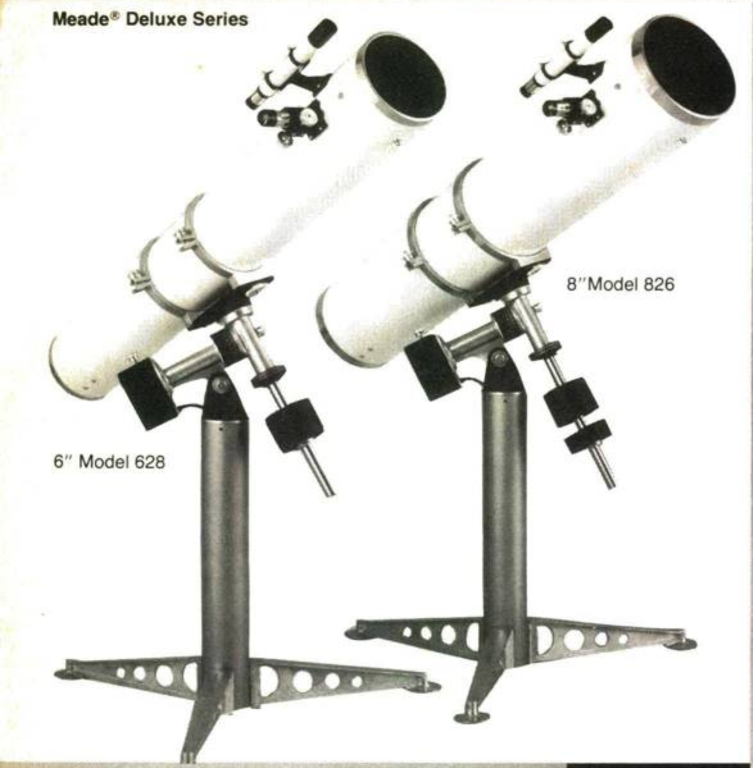
If you take slides, you can greatly enhance the subtle nebular contrasts by making copies of them. A slide duplicator aimed at an ordinary 150-watt light bulb enriches the reds of emission nebulae. Aim the same duplicator at the sky near the Sun, and you can brighten the blues of galaxies, clusters, and reflection nebulae. Experiment with duplicating: try different films and exposures to see which works best. Ektachrome 200 works well for slide duplication.

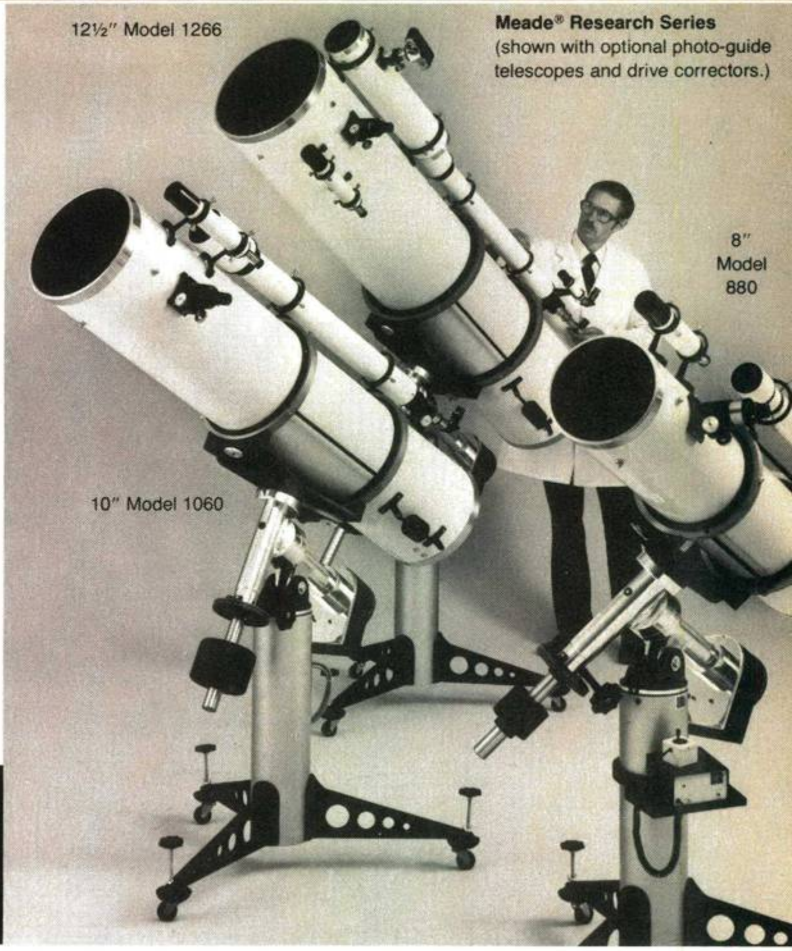
A 4-inch or 6-inch rich field reflector is a powerful astrophotographic tool and can capture spectacular celestial vistas on film with less effort than larger telescopes. Small RFTs are easy to use and highly portable, and when you're tired of photography, you can scan the Milky Way. For wide-field photography, they can't be beat.

Hal Jandorf is a mechanical engineer for Litton Aero Products in Los Angeles and an active observer and astrophotographer. He is involved in several astronomy clubs and teaches observational astronomy at Moorpark College, Pierce College, and the Los Angeles Valley College.

Left: The Rosette Nebula in Monoceros is a large emission nebula complex excited by the cluster of stars in its center. This hypersensitized exposure lasted 45 minutes on Ektachrome 200. Above: Galaxy M-33 in Triangulum shows up well in this 30-minute exposure on hypered Ektachrome 200.

Meade® 6″, 8″, 10″, 12½″ Newtonian Reflecting Telescopes


Meade® Deluxe Series
8″Model 826
6″ Model 628


12½″ Model 1266
Meade® Research Series
(shown with optional photo-guide telescopes and drive correctors.)
8″ Model 880
10″ Model 1060

Meade® Deluxe Series
8″ Model 856
Includes 2″ photo-guide telescope, dual-axis drive corrector, accessory shelf.
(Camera optional)

Meade Deluxe Series 6″ and 8″ Reflecting Telescopes

The most popular reflecting telescopes in the World for the serious amateur. Diffraction-limited 1/10-wave parabolic primary mirrors with matching elliptical flat secondaries. Mounts machined to .001″ tolerances for a lifetime of precision tracking, visually and photographically. Polar and Dec. shafts 1″ dia. solid steel. Complete with Motor Drive (115V./60Hz) and automatic clutch; setting circles; 2 Modified Achromatic eyepieces threaded for filters; 6 x 30 achromatic viewfinder; rack and pinion focuser; rotating ring system. Fiberlite tube with ultrahard white epoxy coating and metal trim rings. Excellent astrophotographic capabilities with your 35mm camera.

Meade Research Series 8″, 10″, 12½″ Reflecting Telescopes

For the advanced observer/astrophotographer, the largest-selling instruments of their kind, by far. Oversize equatorial mounts with double Sealmaster ball-bearings, 1½″ solid steel shafts, 6″ engraved setting circles, and machined Nylon-bearing tube rotation system. Diffraction-limited 1/10-wave optics. Standard accessories: giant #680 focuser for 1¼″ and 2″ O.D.; 8 x 50 viewfinder; 2 multi-coated Orthoscopic eyepieces.

PRICE LIST

COMPLETE DELUXE SERIES TELESCOPES	
Model 628: 6″ f/8 with Motor Drive	$ 519.50
Model 645: 6″ f/5 with Motor Drive	529.50
Model 826: 8″ f/6 with Motor Drive	649.50
Model 856: 8″ f/6 with Motor Drive, 2″ Guide Telescope, Dual-Axis Drive Corrector, Accessory Shelf	979.50
COMPLETE RESEARCH SERIES TELESCOPES	
Model 880: 8″ f/6 with Motor Drive	$1575.00
Model 1060: 10″ f/6 with Motor Drive	1985.00
Model 1266: 12½″ f/6 with Motor Drive	2495.00

COMPLETE EQUATORIAL MOUNTS	
Model 652: 6″ with Motor Drive	$ 225.00
Model 852: 8″ with Motor Drive	260.00
Model 1071: 10″ with Motor Drive	1025.00
Model 1277: 12½″ with Motor Drive	1075.00

All prices **include** packing; F.O.B. Costa Mesa, Calif.

Equatorial Mounts

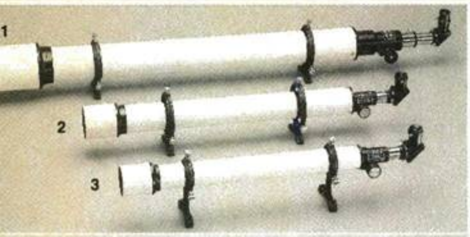
The exact same Equatorial Mounts used on Meade Deluxe and Research Series Telescopes are available for separate purchase. Each mount includes equatorial head with motor drive, setting circles, and saddle plate; pier; tripod legs. Tube cradle rings available optionally.

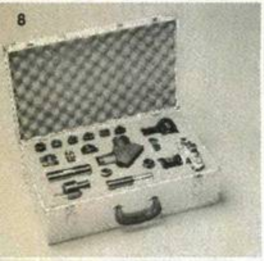
Meade Instruments Corporation

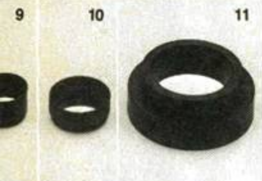
1675 Toronto Way, Costa Mesa, California 92626 □ **(714) 556-2291**

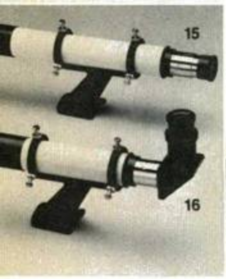
For toll-free dealer locations or factory-direct ordering assistance please turn the page.

Meade® Research Quality Accessories & Parts









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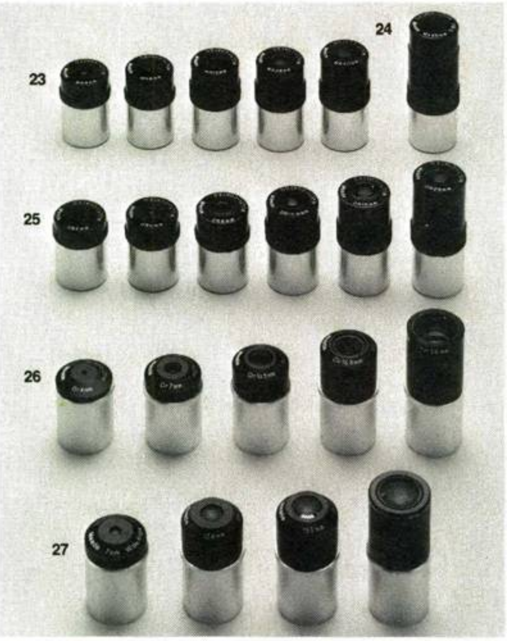
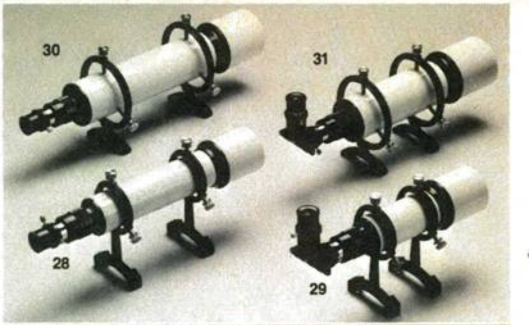
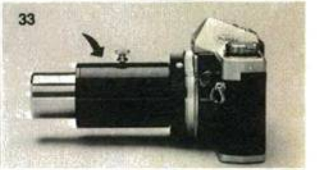
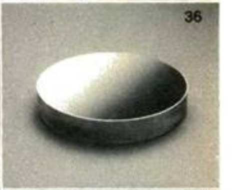
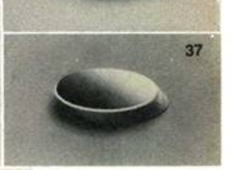










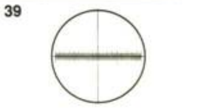


PHOTO-GUIDE TELESCOPES—Each with coated, air-spaced objective, rack-and-pinion focuser, diagonal prism, 9mm crosshair eyepiece.

1—**Model 300PG:** D=80mm (3.1"); F=1200mm (f/15) . . . **$215.00 ppd.**
2—**Model 280PG:** D=60mm (2.4"); F=700mm (f/11.7) . . . **$89.50 ppd.**
3—**Model 210PG:** D=50mm (2.0"); F=600mm (f/12) . . . . . **$69.50 ppd.**
Mounting Rings: for #210PG . . . . per pr. **$12.50 ppd.**
for #280PG, #300PG . . . . per pr. **$14.50 ppd.**

RACK-AND-PINION FOCUSERS—All 3 models include helical-cut rack and variable-tension adjustment for ultra-smooth focusing without backlash. Universal bases fit all tube sizes. Standard 1¼" eyepiece holders.

4—**Model 67**—Strong, lightweight design for 4" to 10" telescopes. 2-3/16" travel. An excellent value. . . . . **$24.95 ppd.**
5—**Model 640** — A heavy-duty deluxe focuser for 6" to 16" telescopes. Full 3" travel for both visual and photographic applications. . . . . **$39.95 ppd.**
6—**Model 680**—Accepts both 1¼" and 2" eyepieces. Full 3" travel for photo or visual observing with 6" to 18" telescopes. . . . . **$49.95 ppd.**

ACCESSORY CASES—For secure storage of eyepieces, Barlows, filters.

7—**Model 54:** Thick-wall polyethylene with latch and handle. Holds 7 eyepieces & Barlow, filters. Dims. 12" x 8" x 3¾" . . . . . **$14.50 ppd.**
8—**Model 50:** Luggage-quality metal case with 2 latches, handle; foam custom fits to your accessories. Dims. 20" x 12" x 6½" **$49.50 ppd.**

NEBULAR FILTERS—*Revolutionary 3-channel filters block natural airglow &* sodium and mercury emissions from city lights. Dramatically improve telescope performance visually and photographically.

9— **Model 907:** 18mm aperture, for .965" O.D. eyepieces . . **$49.95 ppd.**
10—**Model 908:** 23mm aperture, for 1¼" O.D. eyepieces . . **$55.00 ppd.**
11—**Model 911:** 36mm aperture, threads directly onto rear-cell of Meade and other brands of Schmidt-Cassegrains. . . . . **$79.50 ppd.**

12—**PHOTO-VISUAL COLOR FILTERS**—Top quality optical glass, dyed-in-the-mass, with excellent spectral homogeneity. Thread directly into 1¼" O.D. barrels. Filters may be piggybacked. **#8 Light Yellow—#11 Yellow-Green—#12 Yellow—#21 Orange—#23A Light Red—#25A Red—#47 Violet—#58 Green—#80A Blue—Polarizer (30% transmission).** Each **$8.95 ppd.**

13—**VARIPAK DRIVE CORRECTOR—Model 43:** Supercompact 2" x 3" x 4" design. Fast-slow pushbuttons. Variable speed control. Operates from 12 volts D.C., plugs into standard auto cigarette lighter The 12-watt output is sufficient for most telescopes to 14" aperture . . . . **$69.50 ppd.**

14—**VARIGUIDE DRIVE CORRECTOR — Model 41:** The finest R.A. drive corrector available. Includes aircraft-type joystick controller for continuously variable correction rates. Variable speed control. Use with any telescope drive rated up to 12 watts. Operates from 12 v. D.C. or 115 v. A.C. . . . . **$135.00 ppd.**

15—**6 x 30mm VIEWFINDER—Model 631:** Actual field: 4°. Includes coated, achromatic objective lens and crosshair eyepiece. Precise push-pull focusing. Thousands now in use. Bracket with collimation screws and lock-nuts, included. Bracket fits all tubes 6" to 12½". . . . . **$29.50 ppd.**

16—**6 x 30mm RIGHT-ANGLE VIEWFINDER—Model 633:** As in (15), but with prism for convenient right-angle observations. Prism may be rotated 360° for maximum viewing comfort. 2-ring bracket included. . . . . **$36.50 ppd.**

SCHMIDT-CASSEGRAIN ACCESSORIES — The finest obtainable. For Meade and other brands.

17—Tele-Extender . . . . **$22.50 ppd.**
18—Rotary Eyepiece Holder (holds 4 eyepieces) . . . . **$75.00 ppd.**
19—2" Diagonal Mirror (1/10-wave) . . . . **$160.00 ppd.**
20—Off-Axis Guider Body . . . . **$52.50 ppd.**
21—Telecompressor (multi-coated) . . . . **$36.00 ppd.**
22—T-Adapter . . . . **$22.50 ppd.**

23—**SERIES 2 MODIFIED ACHROMATIC EYEPIECES (1¼" O.D.; MULTI-COATED)**—Custom 3-element designs, precisely corrected for chromatic and spherical aberrations. Finest obtainable under $25.
FOCAL LENGTHS: MA 6, 9, 12, 25mm, 40mm Wide-Field, ea. . . . . **$23.50 ppd.**

24—**MODIFIED ACHROMATIC 40mm EXTRA-WIDE-FIELD EYEPIECE (1¼"O.D.; MULTI-COATED)**—Yields widest field obtainable in 1¼" O.D. Enlarged field lens and special field-flattening optics with long eye relief . . . . **$32.50 ppd.**

25—**SERIES 2 ORTHOSCOPIC EYEPIECES (1¼" or .965" O.D.; MULTI-COATED, PARFOCAL)**—The excellent 4-element high resolution optics of these oculars are all the majority of serious amateurs ever require. Razor sharp 45° fields. Both 1¼" and .965" O.D. sets parfocalized.
FOCAL LENGTHS: OR 4, 6, 9, 12.5, 18, and 25mm . . . . **each $32.50 ppd.**

26—**RESEARCH-GRADE ORTHOSCOPIC EYEPIECES (1¼" O.D.; MULTI-COATED; PARFOCAL)**—The largest selling premium-quality eyepieces in the world, universally acclaimed to be the finest eyepieces obtainable. 4-element systems, unsurpassed in color correction, resolution, and flatness of field. 45° field. **OR 4, 7, 10.5 16.8, 28mm** . . . . **each $46.50 ppd.**

27—**RESEARCH-GRADE ERFLE EYEPIECES (1¼" O.D.; MULTI-COATED; PARFOCAL)**—For breathtaking wide-angle observations. 65° fields, parfocalized with our Research-Grade Orthoscopics. **FOCAL LENGTHS: ER 7, 12.4, 15.5, 20mm** . . **each $54.50 ppd.**

VIEWFINDERS — With helical focusers for ultraprecise control of image sharpness. Coated, achromatic objectives of new Meade design yield fully corrected images throughout the field. Actual field on 50mm models: 4¼°, on 60mm models: 3½°. Crosshair eyepiece, dewcap, dustcap included.

28—**8 x 50mm—$52.50 ppd.** Brackets: **$12.50/pr. ppd.**
29—**8 x 50mm RIGHT-ANGLE—$59.50 ppd.** Brackets: **$12.50/pr. ppd.**
30—**GIANT 9 x 60mm—$77.50 ppd.** Brackets: **$12.50/pr. ppd.**
31—**GIANT 9 x 60mm RIGHT ANGLE—$84.50 ppd.** Brackets: **$14.50/pr.**

32—**RESEARCH-GRADE ERFLE 32mm EYEPIECE (2" O.D.; MULTI-COATED)**—Wide-angle, fully-corrected 65° field. The finest eyepiece obtainable in 2" barrel. **$110.00 ppd.** Adapter Barrel for 1¼" O.D. **$12.00 ppd.**

33—**DELUXE CAMERA ADAPTERS**—Adapt your camera to telescope focuser instantly. Individually machined from solid bar aluminum and brass. All units permit both eyepiece-projection and first (prime) focus photography. Specify your camera brand and either 1¼" or .965" focuser. All 1¼" units are threaded for filters. **Nikon, Canon, Minolta, Pentax K, Konica, Olympus OM, or Universal Thread-Mount** . . . . . **$29.50 ppd.**

34—**2X and 3X TELENEGATIVE AMPLIFIERS (1¼" O.D.; MULTI-COATED)**—Warranted without qualification to be the world's finest Barlow lenses. Full 26mm clear apertures. Multi-Coated, with virtually flawless optical corrections at all photo-visual wavelengths on any telescope. **2X Model 122:** . . . **$32.50 ppd; 3X Model 123:** . . . **$35.00 ppd; 2X Model 131:** Per Model 122, but for 965" focusers, 18mm clear aperture, Multi-Coated . . . . **$27.50 ppd.**

35—**2X-3X VARIABLE TELENEGATIVE AMPLIFIER (1¼" O.D.; MULTI-COATED)—Model 127:** Made to same research standards as Model 122 above, but mounted in a machined sliding cell, for variable power settings between 2X and 3X. Engraved scale indicates power. Multi-Coated . . . . **$39.95 ppd.**

36—**PARABOLIC MIRRORS** — The very finest. 1/10-wave, diffraction-limited primary mirrors. Aluminized and quartz overcoated. Immediate shipment. **6" f/8** . . . **$69.50 ppd.; 6" f/5** . . . **$80.00 ppd.; 8" f/6** . . . **$110.00 ppd.; 10" f/6** . . . **$250.00 ppd.; 12½" f/6** . . . **$425.00 ppd.**

37—**SECONDARY MIRRORS** — Elliptical 1/10-wave flats. Aluminized and overcoated. Immediate shipment. **1.30" M.A.** . . . **$13.00 ppd.; 1.52" M.A.** . . . **$17.50 ppd.; 1.83" M.A.** . . . **$21.00 ppd.; 2.14" M.A.** . . . **$24.75 ppd.; 2.60" M.A.** . . . **$29.50 ppd.; 3.10" M.A.** . . . **$52.50 ppd.**

38—**ILLUMINATED RETICLE GUIDING EYEPIECE (1¼" O.D.)**—New phosphorescent etched double-line reticle permits line illumination from dim to extremely bright. Remote brightness control and 6 ft. cable. Modified Achromatic 12mm optical system. Precisely focusable reticle. Complete . . . **$59.50 ppd.** Interchangeable barrel for .965" O.D. . . . . **$7.50 ppd.**

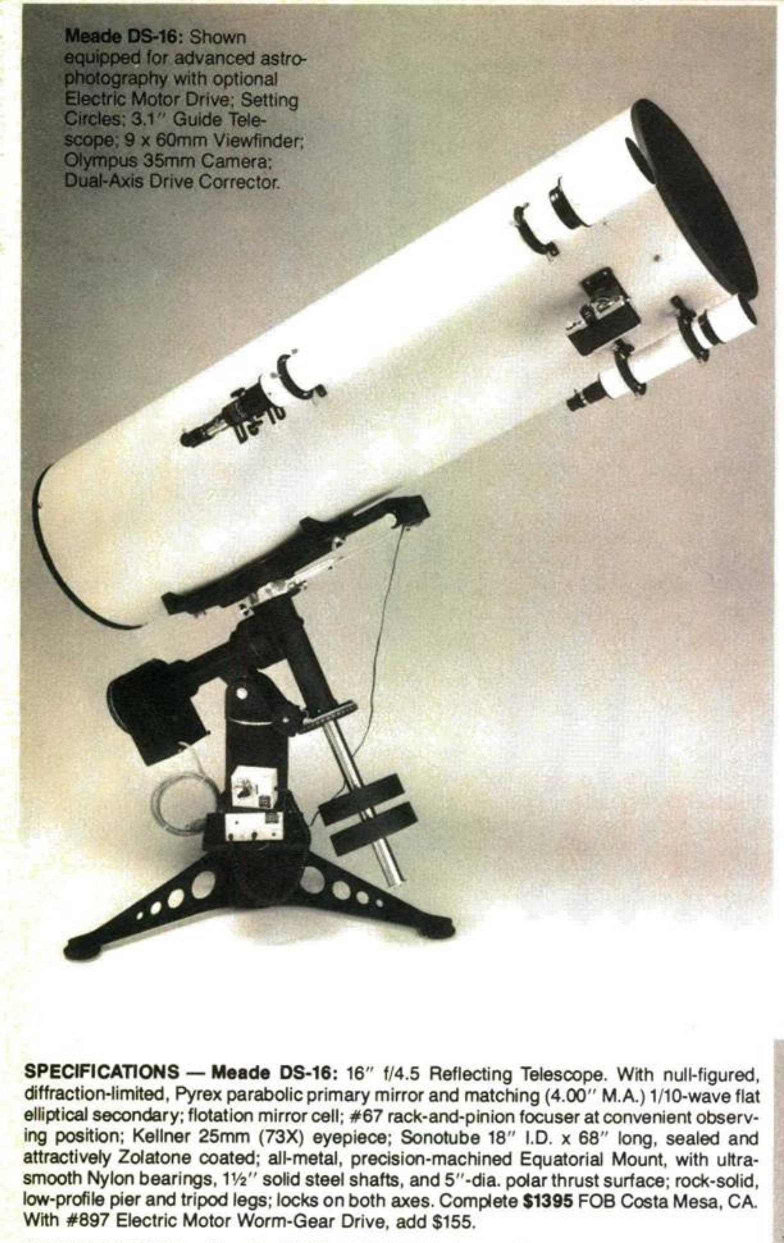
39—**MICROMETER RETICLE**—Full-field scale for accurate measurements of double star separations, planetary angular diameters, etc. Interchanges with standard 4-line reticle of Item (38) above . . . . **$19.50 ppd.**

40—**ERECTING PRISMS** — Fully coated Porro prisms. Invert the astronomical image for terrestrial observations with astronomical telescopes. **1¼" O.D.** . . . **$31.50 ppd.; .965" O.D.** . . . **$29.95 ppd.**

DIAGONAL PRISMS—Optical-quality right-angle prisms, fully coated.

41—**Model 915:** Fits .965" focusers, accepts .965" eyepieces . . . **$24.95 ppd.**
42—**Model 917:** Hybrid diagonal — fits .965" focusers, accepts 1¼" O.D. eyepieces . . . . **$26.95 ppd.**
43—**Model 918:** 18mm clear aperture. Fits 1¼" focusers, accepts 1¼" eyepieces . . . . **$24.95 ppd.**
44—**Model 918A:** 30mm clear aperture. Fits 1¼" focusers, accepts 1¼" eyepieces. Enlarged aperture increases field at low power . . . . **$28.95 ppd.**

Meade® 10″ f/4.5 and 16″ f/4.5 DEEP-SPACE Telescopes



Meade DS-16: Shown equipped for advanced astrophotography with optional Electric Motor Drive; Setting Circles; 3.1″ Guide Telescope; 9 x 60mm Viewfinder; Olympus 35mm Camera; Dual-Axis Drive Corrector.

"The Meade DS-16 is definitely the best astronomical investment I've ever made."

Since their introduction in early 1982, Meade 10″ and 16″ Deep-Space Telescopes have revolutionized the visual observation and astrophotography of Deep-Space objects by the serious amateur. Hundreds of these incredible instruments are now in use throughout the World, with observers continuing to report visual detail never before seen in their experience through amateur-owned equipment.

By combining giant apertures with fast f/4.5 photographic focal ratios, Meade Deep-Space Telescopes permit the capture on film of elusive nebular and galactic detail in 5-to-15 minute exposures—exposure times so short even a beginner can obtain exciting results. Visually, the Meade DS-10 and DS-16 enable observation of subtle blue-green colorations in such objects as the Great Nebula in Orion (M42); inspection of dust lanes in spiral galaxies such as M51 and M101; resolution to the core of the Hercules globular cluster (M13). And, with their rock-solid equatorial mounts, Meade Deep-Space Telescopes virtually eliminate the bothersome backlash and wobble so detrimental to serious observing.

Read what DS-10 and DS-16 owners are saying:

"Observing with the DS-10, I can not praise it enough. For the price, I don't believe it can ever be beaten. Even lunar observing has been fantastic. On deep-sky objects the sky is literally the limit. The DS-10 is also very suitable for double star observations. The wide field of view gives beautiful framing of double stars at lower powers. If you compare the DS-10 to any other scope of equal price, the DS-10 comes out far ahead. It is and will continue to be a pleasure to use."

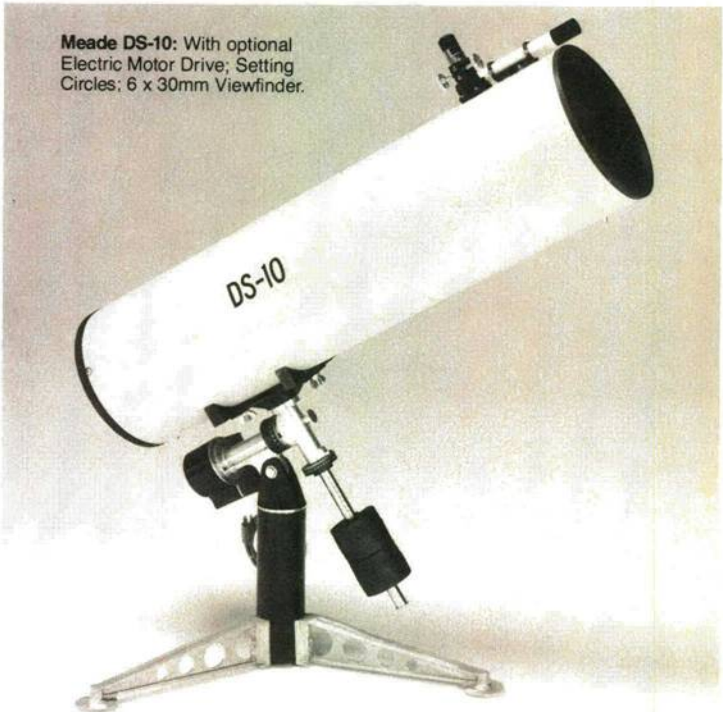
—T. Bosler, Douglasville, PA

"I'm writing to let you know how much I enjoy my DS-16. I can finally see the detail and structure in galaxies that I've only dreamed of before. Last February I got carried away and observed 98 galaxies in one night! M101 is fantastic. The spiral arms seem to go on forever and more than a dozen HII regions are evident. The Meade DS-16 is definitely the best astronomical investment I've ever made."

—B.J. Williams, Houston, TX

SPECIFICATIONS — Meade DS-16: 16″ f/4.5 Reflecting Telescope. With null-figured, diffraction-limited, Pyrex parabolic primary mirror and matching (4.00″ M.A.) 1/10-wave flat elliptical secondary; flotation mirror cell; #67 rack-and-pinion focuser at convenient observing position; Kellner 25mm (73X) eyepiece; Sonotube 18″ I.D. x 68″ long, sealed and attractively Zolatone coated; all-metal, precision-machined Equatorial Mount, with ultra-smooth Nylon bearings, 1½″ solid steel shafts, and 5″-dia. polar thrust surface; rock-solid, low-profile pier and tripod legs; locks on both axes. Complete **$1395** FOB Costa Mesa, CA. With #897 Electric Motor Worm-Gear Drive, add $155.

SPECIFICATIONS — Meade DS-10: 10″ f/4.5 Reflecting Telescope. With null-figured, diffraction-limited Pyrex parabolic primary mirror and matching (2.60″ M.A.) 1/10-wave flat elliptical secondary; #67 rack-and-pinion focuser at convenient observing position; Kellner 25mm (46X) eyepiece; Sonotube 12″ I.D. x 46″ long, sealed and attractively Zolatone coated; all-metal, precision-machined Equatorial Mount, with ultrasmooth nylon bearings and 1″ solid steel shafts; rock-solid, low-profile pier and tripod legs; locks on both axes. Complete **$579.95** FOB Costa Mesa, CA. With #787 Electric Motor Drive, add $75.



Meade DS-10: With optional Electric Motor Drive; Setting Circles; 6 x 30mm Viewfinder.

Toll-Free Dealer Locations & Ordering Assistance

Meade astronomical telescopes, accessories, and other optical instruments are available through hundreds of authorized dealers throughout the U.S.A. and Canada. For the name and address of your nearest Meade dealer, or for factory-direct ordering assistance, call Meade Instruments **toll-free** in the continental U.S.A. (except Calif.):

1-800-854-7485

From all other areas, including California, dial direct **(714) 556-2291.**

All-New 52-page General Catalog—$3.00

Send $3.00 for your copy of the just-revised Meade full-color **General Catalog #83C,** with complete details on the entire range of Meade precision astronomical telescopes, spotting scopes, telephoto lenses, telescope parts, and accessories. Meade General Catalogs are forwarded by return First Class Mail.

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1675 Toronto Way, Costa Mesa, California 92626 □ **(714) 556-2291**

ASTRONEWS

IRAS Keeps Busy

IRAS, the joint United States/-Netherlands/United Kingdom infrared astronomical satellite, has kept very busy recently. On May 13, three weeks after the initial sighting of Comet IRAS-Araki-Alcock (1983d), the satellite picked up another comet, this one known simply as Comet IRAS, 1983f. Unlike 1983d, the new comet is not expected to reach any great luminosity since it approached perihelion on January 20 at a distance of 130 million miles. In June it appeared as a 16th magnitude object in Hydra, and it has since been moving back into the cold depths of the outer solar system.

But IRAS' main objective isn't discovering comets. In completing one third of its all-sky infrared survey, it has also looked at potential star-forming regions in our Galaxy. As the telescope scanned rich Milky Way starclouds, it detected protostars — stars coalescing out of gas and dust — that are just a million years old and probably resemble our Sun as it was about 4.6 billion years ago. The stars are forming out of the huge dust clouds Barnard 5 and Lynds 1642; IRAS spotted as many as five protostars in Barnard 5 and one or two within Lynds 1642. Of course, there is a possibility that planets are also forming around the stars out of the same nebular cloud. In another million years, the enshrouding gas will be driven off by stellar wind and the stars will become visible-light emitters.

IRAS also found that two interacting galaxies — NGC-1888 and NGC-1889 — are powerful infrared sources. This may indicate that a great deal of star formation is occurring in the two huge stellar systems because of the galaxies' interaction. In addition, the satellite scanned M-31, the Andromeda Galaxy, for regions of star formation and with the help of JPL scientists produced a false-color map of these regions.

An Asteroid Bonanza

As recently as a decade ago, asteroids were little more than nuisances. Their major contribution to astronomy was to blunder into photos of more interesting objects. But this attitude finds few supporters today. Observers have learned that these pieces of cosmic debris are fossils left from the formation of the solar system. Someday, these worldlets should reveal secrets of that long-ago birth that have been erased from the surfaces of the planets.

Unfortunately, progress in asteroid research up to now has been painfully slow. But last February, the Infrared Astronomy Satellite (IRAS) began its 10 months of study. Although saying that its data will revolutionize asteroid studies overstates its likely contribution, the satellite nevertheless examines more asteroids in a day than astronomers used to look at in months. At the very least, IRAS is going to save researchers years of work.

Two basic problems slowed the pace of asteroid studies before IRAS. First, the sheer number of these worlds: since 1801 (when the first was found), some 2,900 have been discovered out of a population believed to tally in the tens of thousands. Each body deserves careful attention, but time on telescopes is in great demand and asteroids are only one branch of astronomy among many.

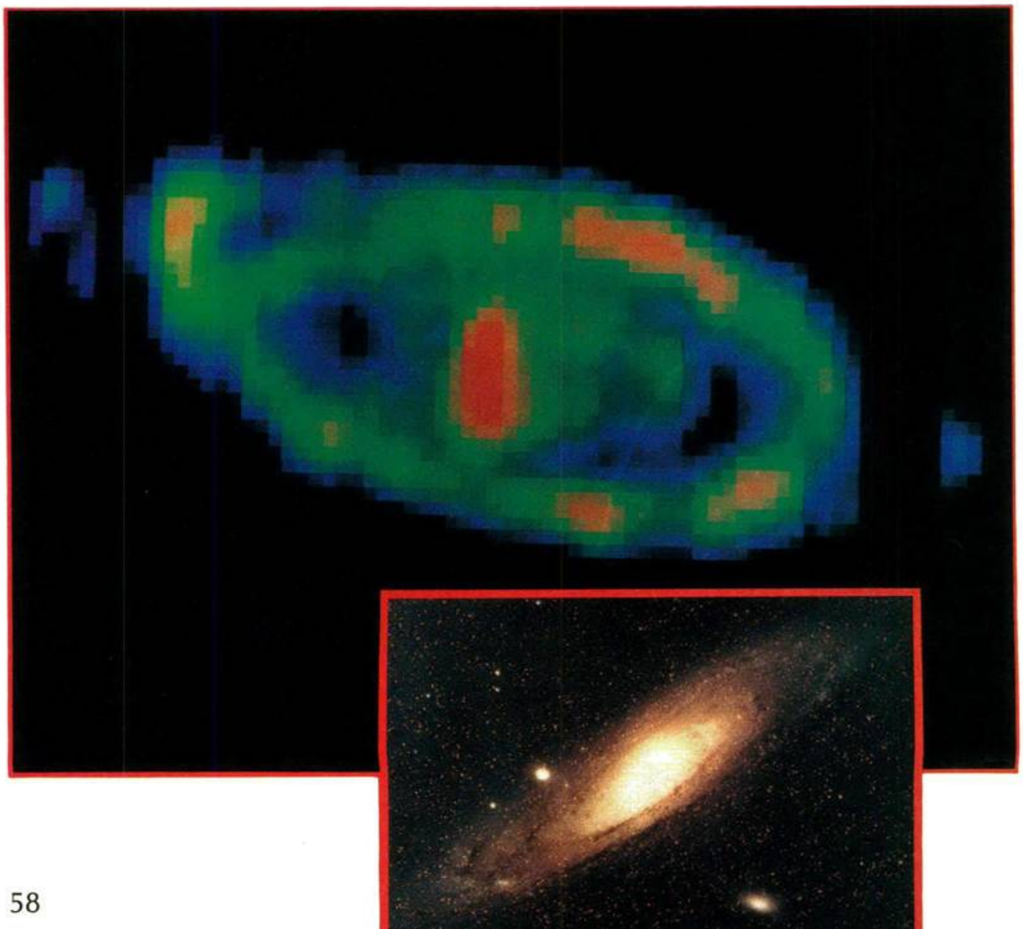
The second problem is related to the first. While researchers have plenty of subjects already on hand, they're limited in the ways they can study them. In theory a multitude of methods are available, from watching asteroids pass in front of stars to probing them with radar. But various problems limit the usefulness of each technique except for the most basic — looking through a telescope to study the light reflected from the object.

One aspect of this method is analyzing the heat emitted by an asteroid. Research at infrared wavelengths can reveal such information as whether bare rock, dust, or boulders covers one of these worlds, and more knowledge can come from combining visual data with infrared. For instance, astronomers who look at a particularly bright asteroid can't tell whether that world is small and shiny or large and dark. But when they compare the amount of visible light reflected with the heat it emits, they can tell both the size and the brightness of the material making up the body. This kind of information allows remarkably sophisticated analyses of the asteroid population.

The Hirayama families are a good example. These groups of asteroids share virtually identical orbits and appear to be fragments of once larger bodies. The pieces frequently have different compositions — a hint that the parent worlds probably formed with layers of different material within them. By adding up the size of bodies made of the same substance, researchers can estimate the percentage of that substance in the original body. By comparing the differences in sizes between pieces of different composition, they can estimate the physical strength of the material of each composition.

Unavoidable water vapor and heat in Earth's atmosphere make infrared studies difficult from ground-based locations. The goal of the IRAS project was straightforward: to get an infrared telescope above the atmosphere where it can study the IR bands with instruments cooled almost to absolute zero, and then to catalogue everything the spacecraft detects.

IRAS' instruments are so sensitive they can detect the warmth of a dust mote a mile away. They could detect a light bulb at the edge of the solar system. Gently warmed by sunlight, asteroids stand out prominently by the tens of thousands in the infrared.



Top: Infrared scan of M-31 recently made by IRAS; blue areas represent regions of faint emission, while green, yellow, orange, and red indicate increasingly more intense IR radiation. The yellow, orange, and red regions reveal that young stars are forming near the nucleus and farther out in the galaxy's spiral arms. JPL photo. Below: Hale Observatories photo of M-31 in optical light.

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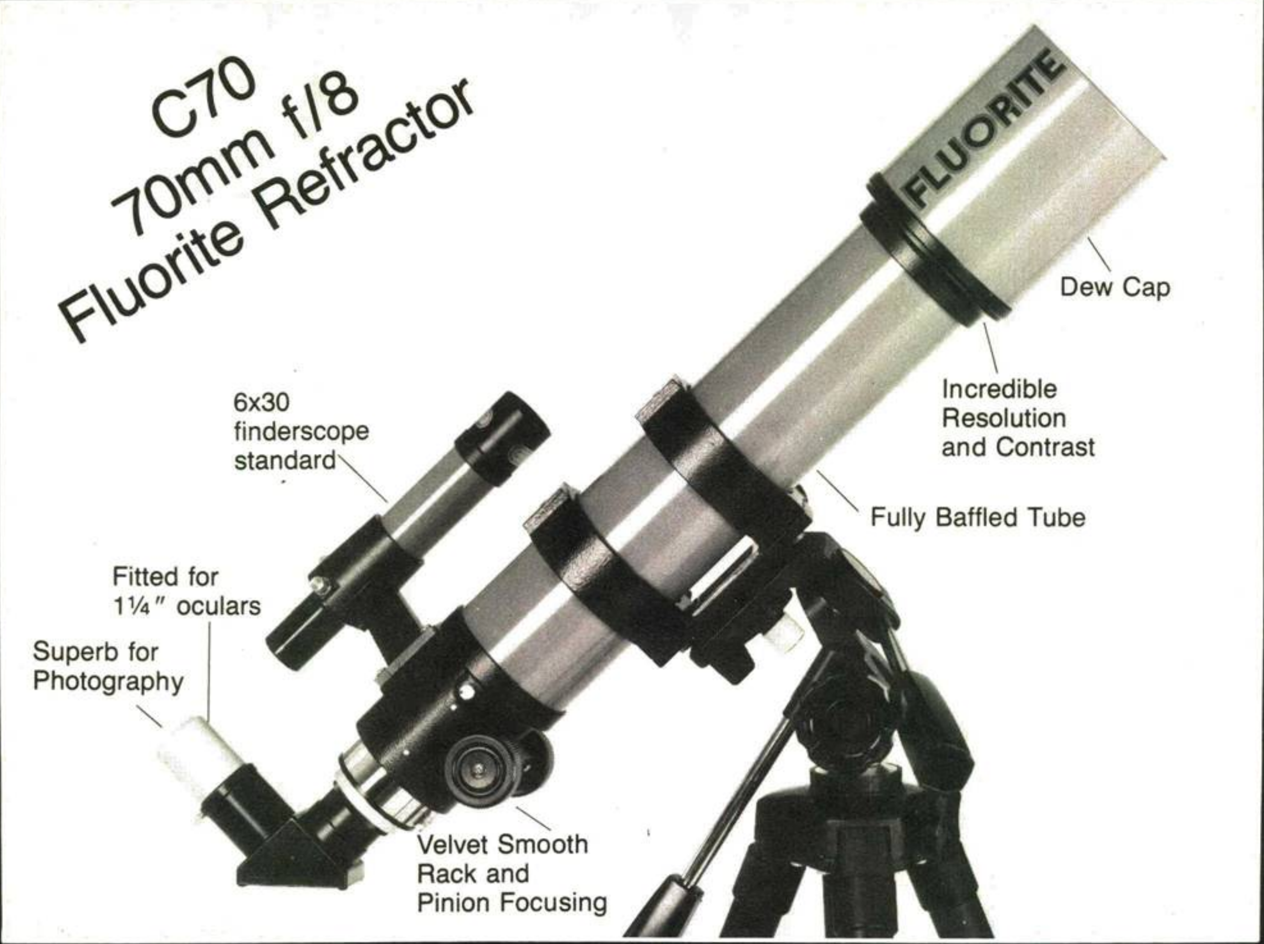
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ASTRONEWS

The astronomers planning the mission developed an elaborate scheme to separate the asteroid sightings from sightings of objects beyond the solar system. IRAS scans the entire sky several times, first a few hours apart and again a few months later. To make it into the deep-sky catalog, an infrared source would have to appear at the same location each time. Asteroids, which move, fail the test, so the data on them go into a separate catalog.

For no more effort than it takes to produce a separate list of the satellite's minor-planet observations, astronomers will have infrared observations for almost every asteroid in the solar system. Collecting the same information from ground telescopes for the 2,900 known worlds would take years. It would have been impossible to do for the yet-undiscovered worlds.

Although IRAS observes thousands of anonymous worlds, it is unable to "discover" them in the special sense that astronomers use the term. Accidentally spotting an asteroid — as IRAS is doing — requires no special effort. Many of these new bodies have probably appeared unnoticed in photographs of the sky already taken. To "discover" an asteroid, however, its orbit must be calculated so that it can be found again for future studies — and IRAS can't provide the information needed to do that. Until each body is tracked by more conventional means, the data from IRAS can be used only for statistical studies.

But if IRAS can't discover asteroids, it certainly can aid in finding them. IRAS returns accurate enough information on each body for an astronomer on the ground to locate it. (Witness its recent comet finds.) Once found, the process of determining the orbit for the asteroid is straightforward. Doing this for *all* the 20,000-odd minor worlds IRAS can see would be an unmanageable task, but the effort is being made for two special classes of these objects.

Most asteroids circle the Sun between the orbits of Mars and Jupiter. A few hundred bodies, however, come inside the orbit of Mars and approach our world. In themselves, these asteroids aren't especially noteworthy. But pieces of them fall to Earth from time to time as meteorites. Analysis of these rocks have taught us much of what we know about asteroids. Unfortunately, researchers often can't tie their samples to a specific type of asteroid, so astronomers hope that IRAS will help them find more of these near-Earth bodies. Then they could better interpret both their telescopic and laboratory studies.

Another asteroid group of interest lies in the outer solar system. The main belt of asteroids records the conditions that prevailed in the inner solar system as the planets formed out of the solar nebula. Locating minor planets beyond Jupiter extends the knowledge farther from the Sun, into regions that are probably more primitive and closer to the original. Finding these bodies, though, has presented substantial technical problems, for they tend to be made of dark material. That gives IRAS an advantage over ordinary telescopes; dark asteroids are bright in the infrared because they are better at soaking up the Sun's heat.

So far, astronomers have found only two of these transjovian asteroids. These are the first of what may prove to be hundreds or thousands in all. If IRAS can turn up *new* asteroid belts, that could revolutionize the entire science. *Van R. Kane.*

Bursts of Cosmic Rays

Cosmic rays are high-energy, electrically charged particles from interstellar space that stream into the atmosphere, smash into gas atoms, and create a cascade of subatomic particles detectable from Earth's surface. About 85% of the particles striking our atmosphere are protons; the remainder are helium nuclei (14%), electrons and positrons (1%), and the nuclei of all elements up to and including uranium (1%).

No one knows where cosmic rays are created — many astronomers believe that the shock waves of supernovae may be responsible. But the results of a recent experiment at the University of Minnesota and the Argonne National Laboratory in Illinois challenge some of the accepted ideas about cosmic rays. The experiment uses a 31-ton detector — designed to watch for the decay of a proton — which sits at the bottom of a 500-meter mine shaft in northeastern Minnesota to shield it from extraneous radiation.

When a high-energy cosmic ray collides with atoms of atmospheric gas, the nucleus fragments and creates a shower of subatomic particles. One of the particles formed in this "air shower" is the muon, a heavy electron. The Minnesota experiment has detected 800,000 of these particles since 1981, and about 5,000 of them occurred in bursts of two or more particles. Some of these muon bursts seemed to be in groups lasting nearly an hour. But the big surprise came with the realization that about 35 groups of the bursts seem to come from two directions: a region including the constellation Cygnus and our Galaxy's north pole. "Nobody seriously looked for these bursts before because nobody thought they could exist," notes Marvin Marshak, the University of Minnesota physicist who announced the finding.

The strange muon bursts might be caused by cosmic ray particles with energies much higher than astronomers had ever thought possible. According to Marshak, the original cosmic rays could arrive in such groups if they hit the upper edge of the atmosphere with energies of 10^{17} electron volts — at least 10 times higher than the highest-energy cosmic rays previously observed.

Another explanation suggests that the cosmic rays responsible for the muon bursts may have normal energies (10^{14}eV) and are reaching us through holes in the galactic magnetic field. If such areas exist, says Marshak, the high-energy particles could come through the holes unscrambled, instead of being swirled into a uniform mush by the Milky Way's magnetic field. "If we are receiving cosmic rays 'straight,' instead of them reeling toward us at random, we could discover where they came from and study their sources, opening up a new branch of astronomy," he remarks.

A third possibility is that the original cosmic ray particles are not electrically charged at all. Energetic, electrically neutral particles could ignore the Galaxy's magnetic field. But finding the reason for the preferred direction of the cosmic rays only pushes the problem further back: What is the origin of the particles?

One possible source, the black hole candidate Cygnus X-1, lies in one of the enhanced areas, but so far there is no way to pinpoint the emission. Soon the Minnesota group will team up with researchers operating other proton decay experiments, searching overlapping areas of the sky to further isolate the muon bursts. A future Space Shuttle mission will loft a satellite designed for a small-scale search for the original cosmic rays. "When the universe is your lab," notes Marshak, "nothing is easy."

Volcanic Ash and Astronomy

Last year, between March 28 and April 4, a volcano in the Mexican state of Chiapas began a series of eruptions. Called El Chichon, the volcano spewed clouds of fine ash into the atmosphere's upper layers, where winds carried them around the world.

By early May, astronomers in Arizona became aware of increasing atmospheric "extinction," a decrease in the intensity of incoming light, apparently caused by a high-level layer of El Chichon's volcanic ash. According to William Livingston of Kitt Peak National Observatory and Wesley Lockwood of Lowell Observatory, the sky transparency at noon was 40% below normal by May 15 — and even casual observers could notice the weakened Sun.

The cloud diminished soon thereafter, although the astronomers note that ash still hampered solar observations that autumn. The sky colors following sunset remained vivid for some time, another reminder of the ash cloud's presence.

Astronomical observations by Livingston and Lockwood show that the ash blocked visible light nearly independent of wavelength at the time of greatest extinction. The depth

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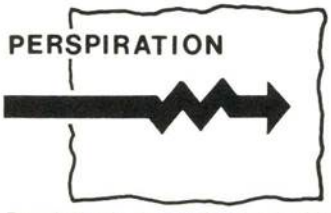

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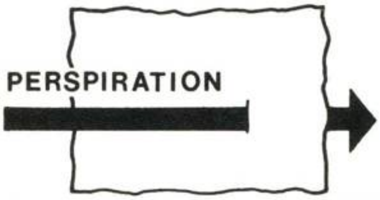

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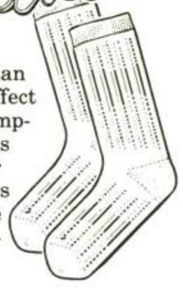

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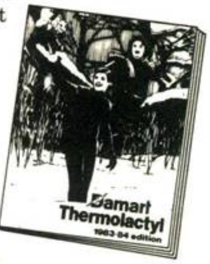

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ASTRO NEWS

of extinction, they point out, actually may have been changing during the several hours required to make each set of measurements. By early June, conditions had returned to those before the maximum decrease — changes that imply a different distribution of particle sizes in mid-May. Stellar photometry measurements indicate an upper limit of one micron for the size of the volcanic particles.

Almost every evening in early May, the astronomers reported, the cloud's striated structure became visible about 10 minutes after sunset. Fine ripple patterns with apparent lifetimes of around one minute formed in certain bands. The Earth's shadow and the "antitwilight arch" were either very weak or invisible in both morning and evening, but the sky developed its deep purple color just 30 minutes after sunset — a twilight finale still visible in October, six months after the passage of El Chichon's dense ash cloud.

Pluto's Coming Eclipses

Pluto's satellite, Charon, was discovered in 1978. Its presence helped astronomers learn more about the solar system's farthest known planet. Now, sometime before 1985, Charon and its partner will begin a series of eclipses — a rare opportunity to gather information on Pluto's mass, size, density, and tenuous atmosphere. (See "Mysterious Pluto," ASTRONOMY, July 1980.)

It's easy to sum up what astronomers now know about Pluto. The planet rotates synchronously with its moon, so the period of Charon's orbit matches the length of Pluto's day — both periods are 6.4 terrestrial days. Pluto's diameter is about one-fourth that of Earth, or about 2,400 miles; the latest mass estimate for the little world is 0.0024 that of Earth. Pluto also has a cold methane atmosphere.

Pluto takes 248 years to orbit the Sun, so astronomers must look now or wait another 124 years for the next series of eclipses. "If there are good enough eclipse data," notes J. Derral Mulholland, a University of Texas research scientist, "they'll provide a good description of the size and shape of both bodies and their surface markings." There's a good chance that neither Pluto nor Charon is completely round, due to their icy composition and close proximity.

Astronomers are not sure exactly when the eclipses will begin, but once they start, they'll continue every 3.2 days for the next several years. Laurence Trafton of the University of Texas says the eclipses should help determine the composition of Pluto's atmosphere. The value of Pluto's radius should improve as a result of eclipse observations, and this in turn will enable more accurate estimates of its surface gravity. "We can see how heavy Pluto's atmosphere must be in order to be gravitationally bound," Trafton says. "With this information," he adds, "we can narrow down gas candidates that might make up the rest of the atmosphere." At present, other possible components of Pluto's atmosphere include argon, neon, nitrogen, oxygen, and carbon monoxide.

ASTRO CALENDAR

September 5-9	**First International Conference on Ethnoastronomy,** "Indigenous Astronomical and Cosmological Traditions of the World." Smithsonian Institution, Washington, DC. Contact: Ethnoastronomy Conference, Center for Archaeoastronomy, University of Maryland, College Park, MD 20742.
September 17	**Astronomy Club of Akron OTAA Convention.** University of Akron, Akron, Ohio. Contact: Phil Hegenderfer, 5070 Manchester Rd., Akron, OH 44319. Phone (216) 644-0230.
September 30-October 2	**Astrofest '83.** Sponsored by the Chicago Astronomical Society. Contact: Astrofest, P.O. Box 596, Tinley Park, IL 60477.
October 1	**Astro-Assembly.** Seagrave Observatory, Peeptoad Rd., North Scituate, Rhode Island. Sponsored by Skyscrapers, Inc. Contact: Gerald Dyck, 418 High Hill Rd., North Dartmouth, MA 02747.
October 8	**Telescope User's Clinic.** Sponsored by the Western Observatorium. Rio Hondo College, Whittier, California. Contact: Western Observatorium, 13215 E. Penn St. #411, Whittier, CA 90602. Phone Bob Ferguson at (213) 795-4181.
October 14-16	**Custer Institute's Astronomy Jubilee.** Southold, Long Island, New York. Contact: Warren E. Hamburger, President, Custer Astronomy Club, Main Bayview Rd., Southold, Long Island, NY 11971. Phone (516) 765-2626.
October 17-20	**15th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society** (professional meeting). Sheraton Conference Center, Ithaca, New York. For information about travel and accommodations, contact: Joseph A. Burns, Space Sciences Building, Cornell University, Ithaca, NY 14853.
October 21-23	**AAVSO Fall Meeting.** Nantucket, Massachusetts. Host institution, Maria Mitchell Observatory. Contact: Janet A. Mattei, AAVSO, 187 Concord Ave., Cambridge, MA 02138. Phone (617) 354-0484.
October 27-29	**Great Plains Planetarium Association Conference.** Hastings, Nebraska. Contact: Mitch Luman, J.M. McDonald Planetarium, 1330 N. Burlington, Hastings, NE 68910.
October 30	**"The Universe Unfolding,"** nontechnical public lecture series, Stanford University, Palo Alto, California. Sponsored by the Astronomical Society of the Pacific. Contact: Stanford Lectures, A.S.P., 1290 24th Ave., San Francisco, CA 94122.
August 1984	**6th World General Assembly of International Union of Amateur Astronomers.** Bologna, Italy. Contact: Dr. Luigi Baldinelli, c/o A.A.B., Casella Postale 1630 AD, 1-40100 Bologna BO, Italy.

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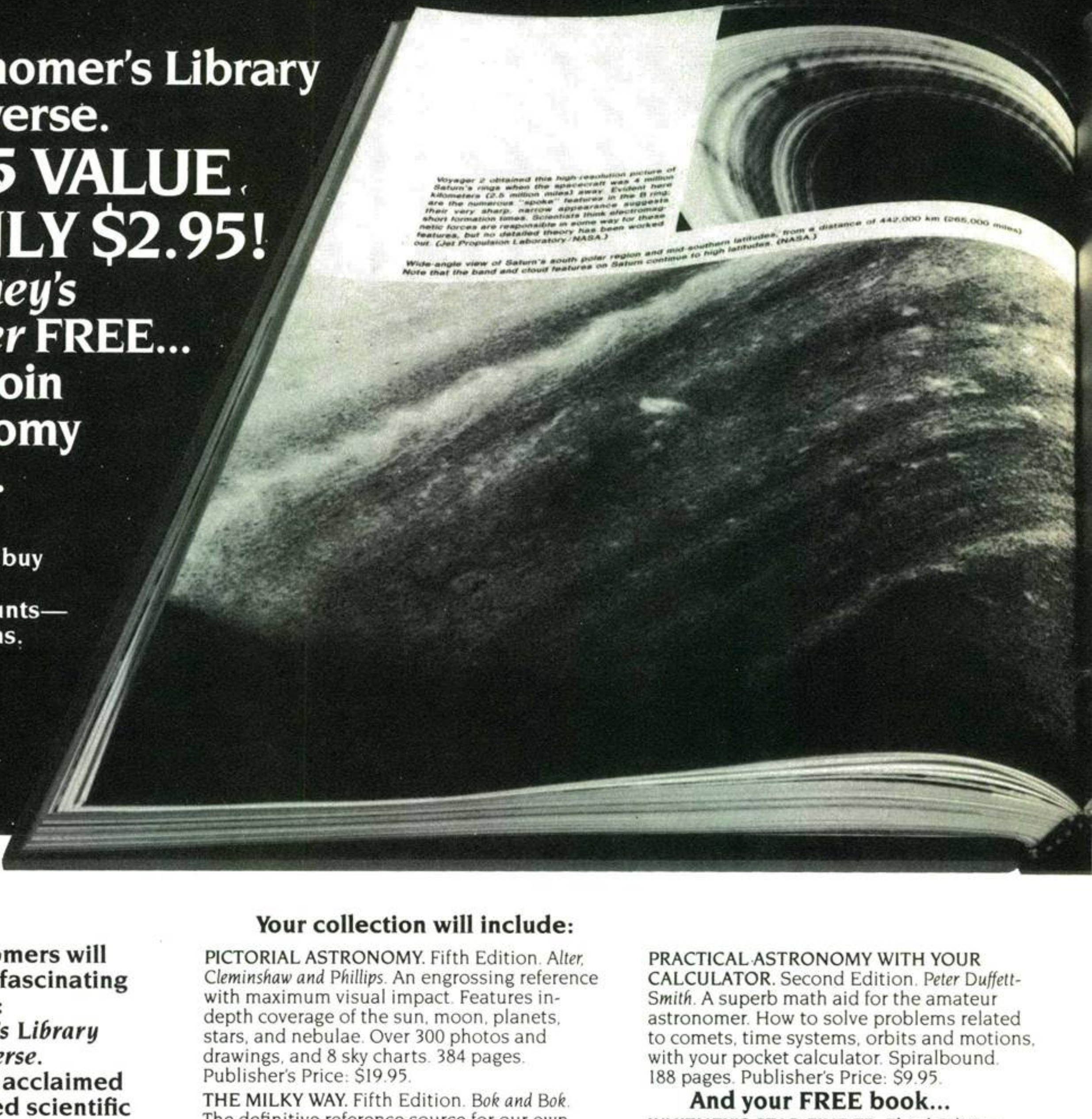

Voyager 2 obtained this high-resolution picture of Saturn's rings when the spacecraft was 4 million kilometers (2.5 million miles) away. Evident here are the numerous "spoke" features in the B ring; their very sharp, narrow appearance suggests short formation times. Scientists think electromagnetic forces are responsible in some way for these features, but no detailed theory has been worked out. (Jet Propulsion Laboratory/NASA.)

Wide-angle view of Saturn's south polar region and mid-southern latitudes, from a distance of 442,000 km (265,000 miles). Note that the band and cloud features on Saturn continue to high latitudes. (NASA.)

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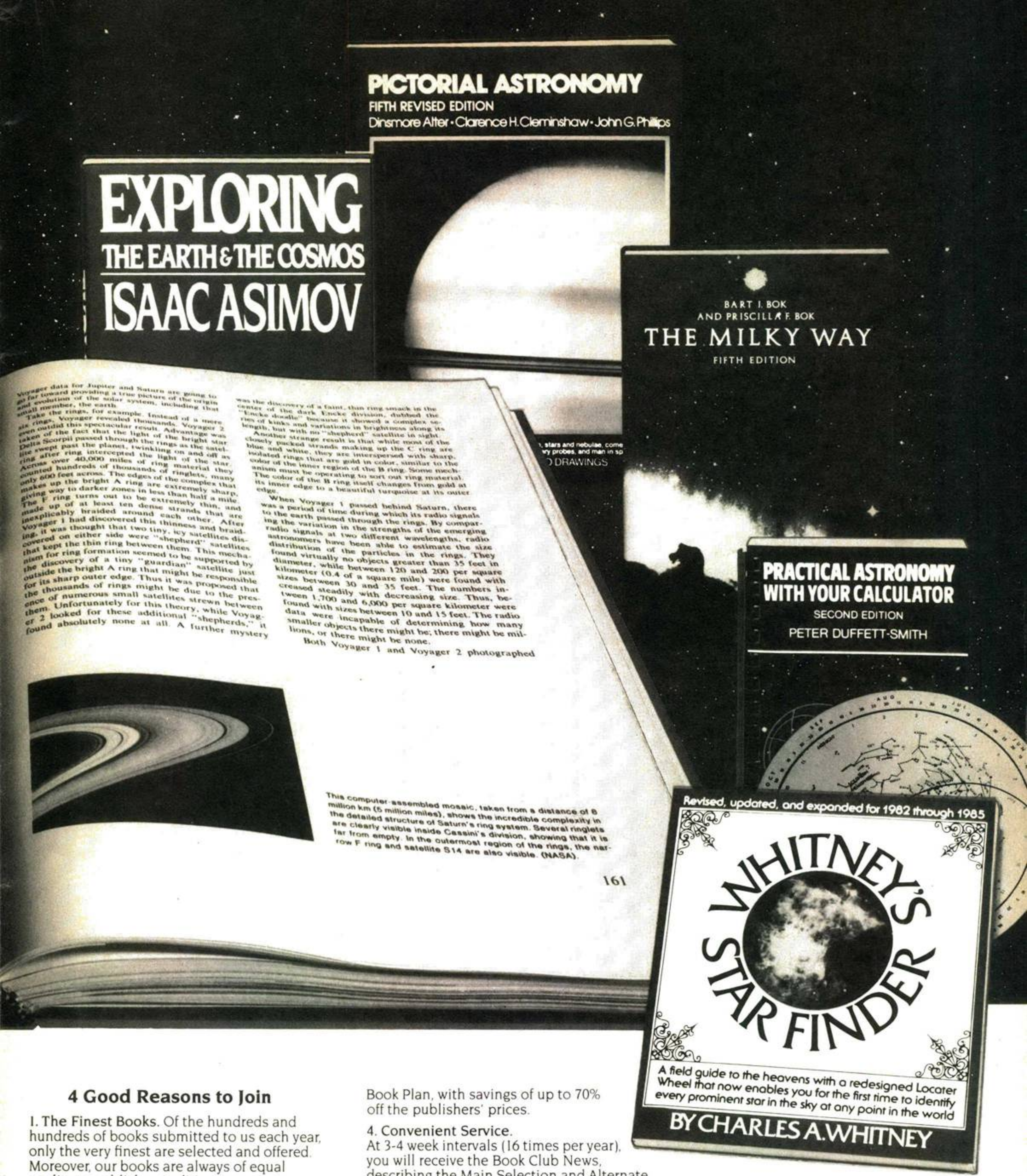
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A field guide to the heavens with a redesigned Locater Wheel that now enables you for the first time to identify every prominent star in the sky at any point in the world
BY CHARLES A. WHITNEY

Voyager data for Jupiter and Saturn are going to go far toward providing a true picture of the origin and evolution of the solar system, including that small member, the earth.

Take the rings, for example. Instead of a mere six rings, Voyager revealed thousands. Voyager 2 even outdid this spectacular result. Advantage was taken of the fact that the light of the bright star Delta Scorpii passed through the rings as the satellite swept past the planet, twinkling on and off as ring after ring intercepted the light of the star. Across over 40,000 miles of ring material they counted hundreds of thousands of ringlets, many only 600 feet across. The edges of the complex that makes up the bright A ring are extremely sharp, giving way to darker zones in less than half a mile. The F ring turns out to be extremely thin, and made up of at least ten dense strands that are inexplicably braided around each other. After Voyager 1 had discovered this thinness and braiding, it was thought that two tiny, icy satellites discovered on either side were "shepherd" satellites that kept the thin ring between them. This mechanism for ring formation seemed to be supported by the discovery of a tiny "guardian" satellite just outside the bright A ring that might be responsible for its sharp outer edge. Thus it was proposed that the thousands of rings might be due to the presence of numerous small satellites strewn between them. Unfortunately for this theory, while Voyager 2 looked for these additional "shepherds," it found absolutely none at all. A further mystery was the discovery of a faint, thin ring smack in the center of the dark Encke division, dubbed the "Encke doodle" because it showed a complex series of kinks and variations in brightness along its length, but with no "shepherd" satellite in sight.

Another strange result is that while most of the closely packed strands making up the C ring are blue and white, they are interspersed with sharp, isolated rings that are gold in color, similar to the color of the inner region of the B ring. Some mechanism must be operating to sort out ring material. The color of the B ring itself changes from gold at its inner edge to a beautiful turquoise at its outer edge.

When Voyager 1 passed behind Saturn, there was a period of time during which its radio signals to the earth passed through the rings. By comparing the variation in the strengths of the emerging radio signals at two different wavelengths, radio astronomers have been able to estimate the size distribution of the particles in the rings. They found virtually no objects greater than 35 feet in diameter, while between 120 and 200 per square kilometer (0.4 of a square mile) were found with sizes between 30 and 35 feet. The numbers increased steadily with decreasing size. Thus, between 1,700 and 6,000 per square kilometer were found with sizes between 10 and 15 feet. The radio data were incapable of determining how many smaller objects there might be; there might be millions, or there might be none.

Both Voyager 1 and Voyager 2 photographed

This computer-assembled mosaic, taken from a distance of 8 million km (5 million miles), shows the incredible complexity in the detailed structure of Saturn's ring system. Several ringlets are clearly visible inside Cassini's division, showing that it is far from empty. In the outermost region of the rings, the narrow F ring and satellite S14 are also visible. (NASA).

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X-RAYS FROM STARS

by
Leon
Golub

The Sun is the strongest source of radiation in the sky at nearly all wavelengths, from radio through visible light to X-rays. The human eye has evolved to use that portion of the Sun's spectrum where the radiation is maximum, and by far the largest part of the Sun's energy output falls into the very narrow interval centered around the visible wavelengths. However, the Sun emits energy in forms other than visible light. Even though this invisible radiation is but a small fraction of the Sun's total output, some of it may have significant effects on our terrestrial environment.

As is true for most stars, the temperature of the Sun's surface determines the character of the radiation it emits. The spectrum of energy radiated by the Sun results from its 6,000° K surface temperature, which is determined by the balance between the amount of energy generated by nuclear fusion deep in the solar interior and the ability of its surface to disperse this energy.

The thermonuclear processes in the Sun's core that generate its energy are sensitive to stellar mass, since this determines the temperature and pressure of the region where the star burns its nuclear fuel. At the same time, the star's surface area is a major factor in determining the star's ability to rid itself of the energy produced by nuclear fusion. But the relation is not simple since stellar surface area does not increase drastically with increasing stellar mass. The end result: relative to their size, low mass stars do not have as much energy to radiate away as more massive stars, yet since they have as much area as high mass stars, their surfaces must be cooler. Astronomers think of the Sun as an example of a small, cool star. Such stars have surface temperatures lower than about 10,000° K and colors ranging from yellow to red.

A question of major concern to us is how the Sun's energy output varies. After all, our living conditions can be strongly affected by relatively small changes in any of a number of factors. At the most basic level, the temperature of Earth would be lower than that of the outermost planets without the Sun. Conceivably, even a small change in the Earth-Sun distance could have made our planet similar to Mars or Venus. The favorable climate we enjoy comes from a delicate balance between heating and cooling forces, and small or subtle changes in this balance could produce large and unpredictable effects.

Of course, the fairly long span of recorded history proves that catastrophic effects have not taken place recently. But episodes like the period of severe winters in North America and Europe known to have occurred during the colonization of the New World show that *some* variation can happen. This period seems to be associated with the disappearance of the normal cycle of solar activity for nearly a century, the so-called *Maunder minimum*. In some as yet unexplained way, the reduced number of sunspots and related activity seems to have made our weather much worse than average. (See "The Case of the Missing Sunspots," ASTRONOMY, February 1981.)

In contrast, evidence from glacial sedimentary deposits in Australia shows that the solar cycle existed essentially unchanged tens of millions of years ago. The exact level of solar activity can't be deduced from these records, but a periodicity in the thickness of the layers indicates a cycle, and the number of layers reveals the number of years in the cycle. The level of solar activity seems to have influenced the rate of glacial melting at the Australian site, producing a change in the deposition rate of the sedimentary layers throughout the 11 or so years of each solar cycle. These deposits show that the average length of the cycle and some of its properties were the same then as they are today! Any theories that claim that the Sun changes on time scales of a million years or less must deal with this evidence. Moreover, there are tens of thousands of years of these layers, providing an unsurpassed opportunity to study the solar cycle in a way unmatched by today's measurements, which cover only a few hundred years.

In visible light, the changes related to solar cycle activity are small and difficult to detect. But if we go to other parts of the spectrum, the signatures of activity appear with greater contrast. They are still small compared to the photosphere's steadier output, but the photospheric background is greatly reduced at X-ray or radio wavelengths, and the activity stands out more clearly.

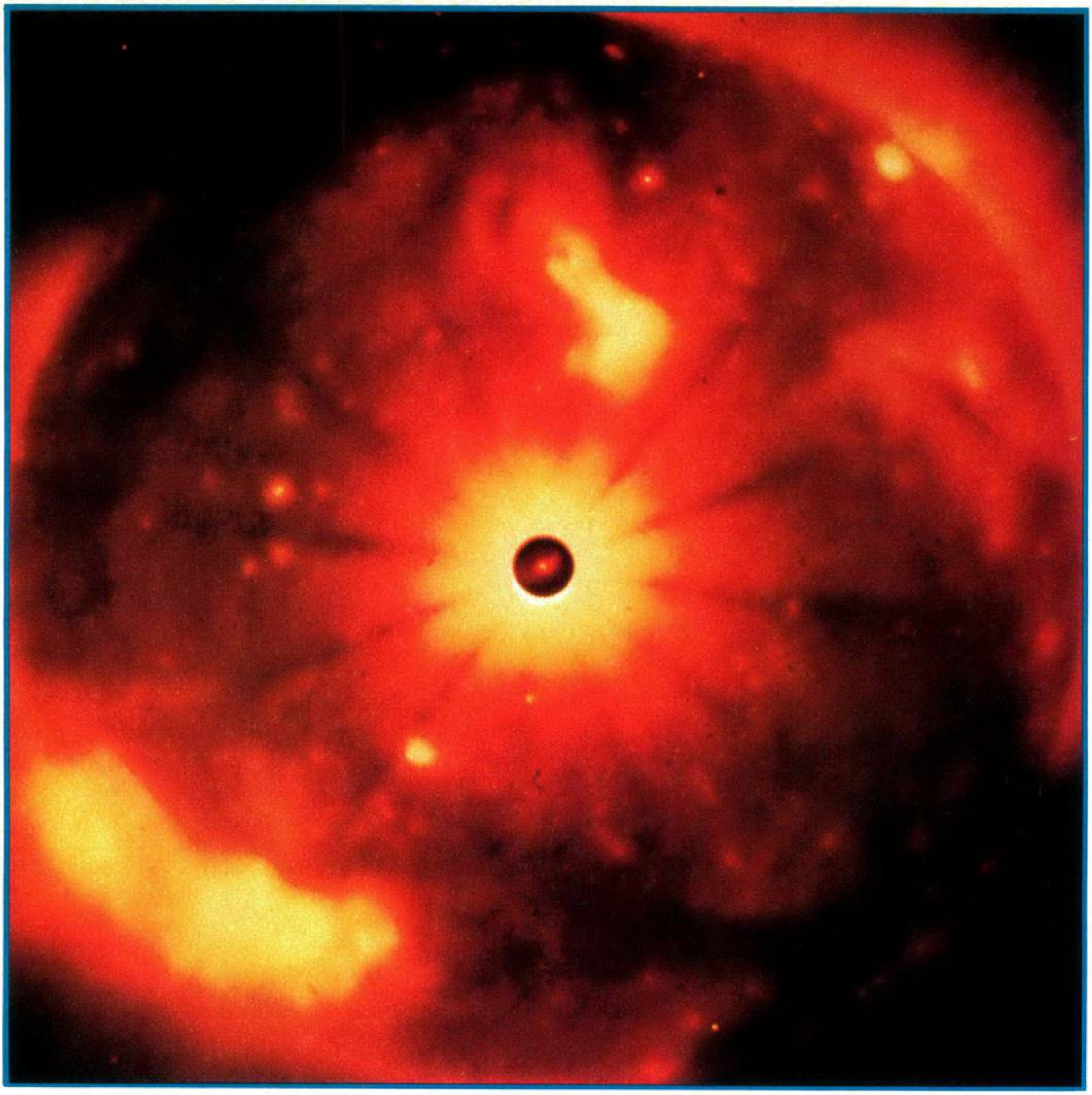
For the activity-related emission to stand out from the photospheric spectrum at certain wavelengths, it must have a spectrum different from that of the photosphere. This difference exists mainly because the activity is closely linked to the emergence of strong magnetic fields from within the Sun. When these fields emerge, they produce an extended region of emission with very high temperature but very low energy density — the corona (see "What Heats the Solar Corona?" ASTRONOMY, September 1982). The ionized gas of the corona reaches temperatures of several million degrees, but the total emission from the corona is much lower than that of the photosphere since it contains far fewer particles.

The presence of a high-temperature plasma contained by strong magnetic fields and extending to great heights above the solar surface produces emission at both ends of the electromagnetic spectrum. At the high-energy end, a three-million-degree plasma emits radiation in X-rays. The 6,000° K photosphere, on the other hand, produces negligible emission at X-ray wavelengths. Thus activity can be identified very easily by its X-ray signature.

Magnetic activity on the Sun also produces emission at radio wavelengths. The million-degree gas in the corona is confined and probably heated by the intense magnetic fields. Due to its high temperature, the coronal gas is ionized, and many of the electrons are free of their confining atoms. Electrons are easily deflected by coronal magnetic fields, and their abrupt motion produces radio emission. Both the coronal temperature and the strength of the magnetic fields determine the frequency of the radio emission. So at both ends of the electromagnetic spectrum, there are clear signs of activity closely linked to magnetic fields on the solar surface.

Magnetic fields are the central ingredients governing solar activity, and are important in producing much of the energetic phenomena encountered in nearly all areas of astrophysics (see "Sunspots," ASTRONOMY, May 1980). The knowledge we gain from studying the solar corona can be applied to many other astrophysical problems, ranging from accretion disks around compact X-ray sources to the heating of the gas inside clusters of galaxies. The lessons we are learning from our own star are useful in many areas, often in ways that could not have been anticipated only a few years ago.

The production of magnetic fields in astrophysical objects

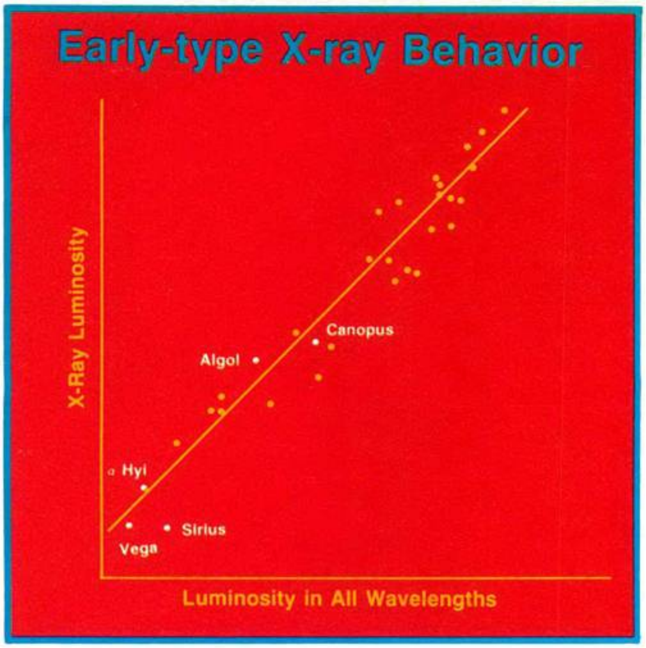


Regions of flare activity are overexposed in this image of the X-ray Sun. The short exposure inset reveals one flare's location. Courtesy Leon Golub.

is the subject of active study and debate among astronomers. The difficult mathematical calculations and computer simulations that make up the core of these studies are generally grouped under the title "dynamo theory." In its most basic form, the theory describes the generation of magnetic fields by the familiar induction effect: a conductor forced to move through a magnetic field generates an electrical current. Since the currents produced by moving the conductor will themselves produce magnetic fields, the slightest amount of magnetic field initially present becomes amplified by motions of the fluid. This induced field adds on to the pre-existing field, and thus can amplify itself.

We know that magnetic fields emerge from within the Sun. It is commonly presumed that they are somehow generated by a magnetic dynamo operating in the solar interior. The patterns of fluid motion inside the Sun seem to allow field amplification. In fact, dynamos must be fairly easy to produce in nature since many of the bodies in our Solar System, such as the Earth and Jupiter, have measurable magnetic fields. Moreover, all stars that are like the Sun seem to have X-ray emission, which suggests the presence of magnetic fields and, in turn, magnetic dynamos. So even though an acceptable mathematical description of the solar dynamo has so far eluded astrophysicists, nature doesn't seem to have a problem producing magnetic fields.

The emergence of magnetic fields from inside the Sun produces the entire host of effects that we collectively term solar activity, ranging from a local cooling and darkening of the photosphere — a sunspot — to the violent eruptive events known as flares. Surface magnetic fields are also responsible for the corona's structure and are probably its source of heat. For example, astronomers have known for nearly two decades that the corona is brightest and hottest at those locations occupied by strong magnetic fields. We now believe that the magnetic field heats coronal plasma, in addition to confining it. How can magnetic fields heat a plasma? Locally dissipated electric currents



The X-ray emission from stars between spectral types B3 and A5 makes up about one ten-millionth of their total radiation. This "early-type behavior" continues down to stars only slightly larger and hotter than the Sun. But the way early stars generate X-rays — stellar wind — is practically non-existent in stars like the Sun.

(resistance heating as in an ordinary light bulb) or a type of frictional heating caused by plasma motions induced by the magnetic field may be responsible. In either case, there is a definite link between the existence of magnetic fields at the solar surface and the intense X-ray emission radiated away by the corona.

Why study solar X-rays? First, we can see directly coronal activity and the manner in which magnetic fields control and direct that activity. Second, we can learn about the production of magnetic fields in the Sun by looking at fields emerging from its interior. In recent years, the availability of high-resolution X-ray data has contributed to a major change in our understanding of both areas. Our ability to see X-ray emission from other stars now provides us with an entirely new and exciting testing method. The wider range of conditions found on other stars offers more stringent tests for theories derived in the context of our Sun.

Launched in 1978, the Einstein Observatory greatly improved our ability to detect X-ray emission from stars. This satellite-borne instrument carried a large X-ray imaging telescope and a set of instruments at its focal plane. Each of the instruments could be moved into or out of position for detecting incoming X-rays. The satellite's capabilities were substantially greater than earlier instruments; it boasted a large collecting area, a sharply focused image, and the ability to point at a source for an extended period of time. As a result, Einstein increased the effective sensitivity to stellar X-rays by a factor of 1,000 over previous experiments.

Einstein has provided us with a unique opportunity to study with greatly increased sensitivity the coronal emission from stars. As it happens, the increase was just large enough to completely change our previous conceptions about the nature of stellar X-ray emission. Data from Einstein allow us to survey a sample of stars large enough for detailed comparative studies between the Sun and other solar-type stars.

Before the launch of the Einstein Observatory, scientists expected that the level of X-ray emission in the solar corona was typical of other stars. In fact, theories of coronal formation and heating predicted that we would find the Sun to be a relatively strong emitter compared to most other stars. At that time, astronomers believed that the corona was heated by the dissipation of acoustic waves generated in the turbulent gas at the solar surface. This type of surface turbulence is not present at the same level in all stars; on the contrary, stars with masses close to that of the Sun produce the highest flux of acoustic energy. Hotter, larger stars and smaller, cooler stars were both expected to show less coronal emission than the Sun.

Observations show that just the opposite is true — the Sun is a comparatively *weak* X-ray emitter! Perhaps more surprising, nearly every type of star emits X-rays at a level comparable to or greater than that of our Sun. The observed emission ranges from 10,000 times as strong, in the case of large, hot O stars, to several times lower than the Sun for very small, old red dwarfs such as Barnard's Star. Even some stars of the same spectral type as the Sun are relatively strong X-ray emitters, such as the type G dwarf 1 Ursae Majoris. The only normal stars that do not seem to emit X-rays at a detectable level are white dwarfs, although even here there are a few exceptions. Sirius B, for example, is a relatively strong emitter. Low mass red giant stars, like Betelgeuse, may not produce substantial X-ray emission either. But there are no red giants very close to us, so we haven't been able to test their emission at a sufficiently low level of sensitivity. For the present, evidence indicates that red giants do not emit more X-rays than the Sun.

At this point, the obvious question is: Why do so many stars emit X-rays? The fact that the observations so strongly disagree with previous expectations is a profound puzzle — just the type of intellectual challenge that often follows the first use of a new instrument. Fortunately, progress in understanding the solar corona has come at the right time to help us explain some of the new stellar data. Our solar theory can explain, in a qualitative way at least, the X-ray observations of the entire range of evolved stars generally known as "late-type." Unfortunately, though, the presence of X-ray emission from the larger, hotter "early-type" stars is still a complete mystery.

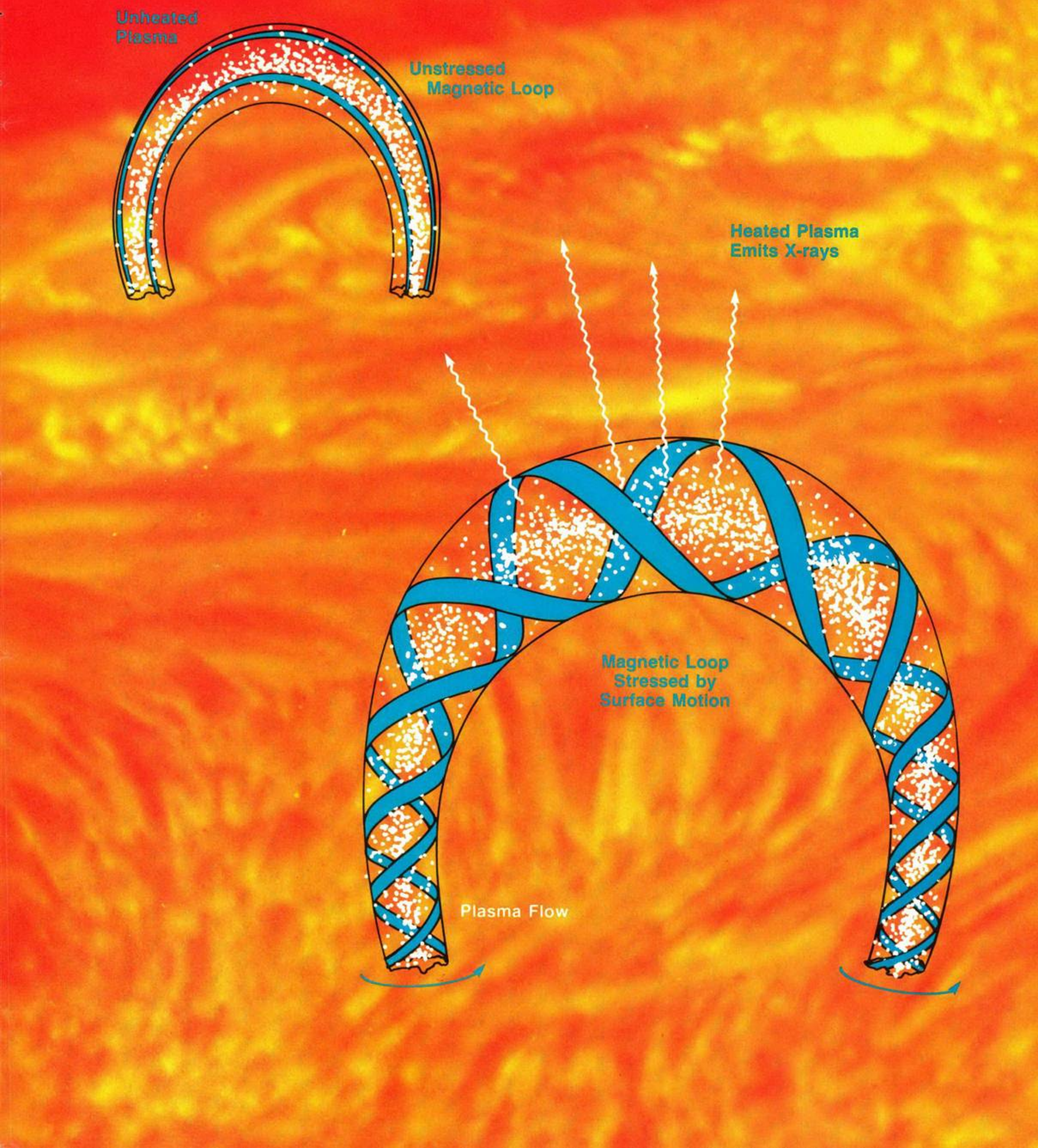
The character of X-ray emission observed from normal stars cleanly divides into two types of behavior. For stars larger than about 1.5 solar masses, the X-ray emission is always a fixed fraction of the star's total luminosity. For all stars of this size or larger, X-ray emission amounts to one ten-millionth of the star's total energy output. Moreover, the observed X-rays are not merely an outcome of the 10,000° to 30,000° K surface temperature of these stars. Rather, the emission clearly comes from material at very much higher temperatures of several hundred thousand to millions of degrees.

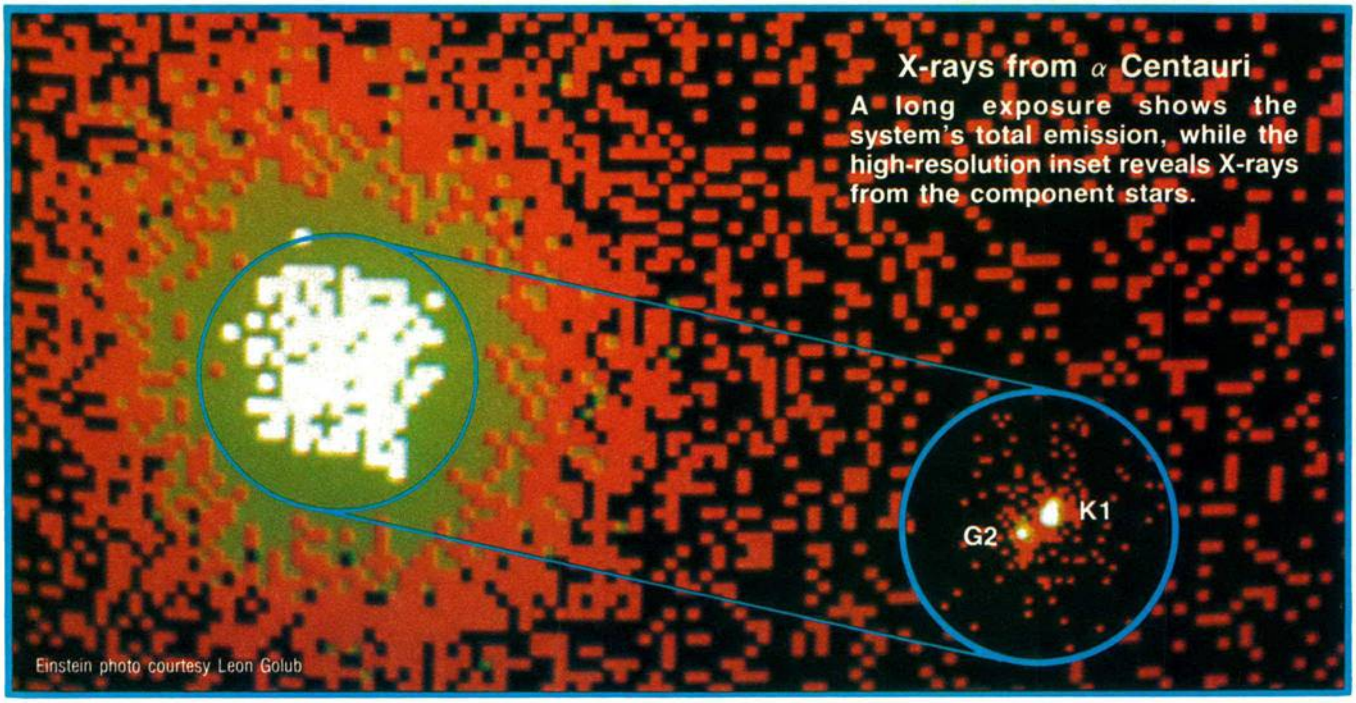
The highest mass stars (also the brightest and hottest) at least offer a conceptual mechanism to explain X-ray production. These stars lose mass at a relatively fast rate, blowing material from their surfaces at great speed. The pressure from radiation of a star's hot photosphere drives such a stellar wind. In theory, these winds flow so rapidly that they will eventually produce shock waves around the star — shock waves with sufficient energy to produce the high temperatures responsible for X-ray emission. Astronomers have developed this general model, which explains rather well the observed properties of the X-ray emission from very hot, high-mass stars. But "early-type behavior," in which the star emits a fixed fraction of its energy in the form of X-rays, continues all the way down the scale to stars only slightly larger and hotter than the Sun. Unfortunately these lower mass stars have negligible stellar winds. The mechanism invoked for younger, hotter stars shouldn't work with such feeble stellar winds — yet these stars *do* have X-ray emission.

There does not appear to be a suitable alternative explanation at the moment. The full set of observations is only now becoming available; theorists have not had enough time to attempt an explanation. At least for the present time, we'll have to accept the fact that our observations cannot yet be fully explained — and the additional possibility that the entire theory may turn out to be wrong when all the data are understood.

In terms of our overall explanation of the high temperatures observed, the situation for the so-called late-type stars is far more satisfactory. At the same time, the theory itself is inherently more complicated than that for early-type stars, which makes the job of testing it very difficult.

Heating with Magnetic Fields


Unheated Plasma
Unstressed Magnetic Loop
Heated Plasma Emits X-rays
Magnetic Loop Stressed by Surface Motion
Plasma Flow



X-rays from α Centauri

A long exposure shows the system's total emission, while the high-resolution inset reveals X-rays from the component stars.

Einstein photo courtesy Leon Golub

We now have a large quantity of data on coronal emission from stars like the Sun and from the numerous lower mass stars in the solar neighborhood. From this information, X-ray emission seems to be a common phenomenon. Moreover, the measurable characteristics of the coronae on these stars show that they are similar to our own Sun in terms of emission strength and plasma temperature. In addition, these stars show Sun-like forms of variability, from X-ray flares to the long-term cyclical behavior characteristic of changing levels of activity. These new observations from satellites like Einstein and the International Ultraviolet Explorer strongly support the idea that magnetic fields are directly involved in a star's coronal X-ray emission. Remember that this theory was based on detailed observations of the solar corona, but it was developed at precisely the right time to help explain how small, cool stars only one-tenth the size of the Sun could produce up to 1,000 times more X-rays.

The key to the explanation appears to lie in the production mechanism for magnetic fields. What conditions are required to produce magnetic fields in stars? At least one answer seems to be that magnetic dynamos will operate in any star that rotates and has an outer convection envelope, such as the hydrogen convection zone found on the Sun. This zone, a turbulence in the outer 20 percent or so of the Sun's volume, is driven by nuclear energy from the stellar core in its attempt to escape. Ordinary thermal conduction is not efficient enough to carry away all the energy from the Sun's nuclear furnace. Another process of heat transfer, called convection, is required. Hot material rises to the surface, cools off, and sinks back down into the hot solar interior. If we examine main-sequence stars in order of decreasing mass, which is equivalent to decreasing surface temperature, we find that the first shallow convective zones begin in stars slighter larger than one solar mass and continue on down to the smallest red dwarfs. The red dwarfs are thought to be fully convective — the convective zone encompasses the entire volume of the star.

From new space observations, it now appears that the requirements for the existence of a magnetic dynamo are an outer convective zone and rotation. The dynamo will then generate fields inside the star that float up to the surface. Once the fields reach the surface, the convective motions induce stresses within them. These stresses dissipate by spreading up into those portions of the field that extend above the star's photosphere, resulting in the formation and heating of a corona around the star. Or so the scenario goes.

This tentative scheme provides a natural, if somewhat involved, explanation for our observations of coronal emission from late-type stars. But detailed solar work has provided specific predictions relating the observed X-ray emission to the strength of the magnetic field in the emitting regions. Such observations provide a stringent check on the theoretical ideas, lending more credence to the concept of magnetic heating for the solar corona. As for the stars, we not only have the new coronal observations, but can now obtain direct measurements of stellar magnetic fields.

Improvements in ground-based instrumentation and in analysis techniques make it possible to detect magnetic fields on nearby solar-type stars, particularly those that are very strong X-ray emitters. Although this information is just now becoming available, some early tests show encouraging results. For example, astronomers have used X-ray data to predict the magnetic field strength on an active star called Lambda (λ) Andromedae, a nearby subgiant. About seven times as large as the Sun, this star rotates very rapidly due to the presence of an orbital companion. The rapid rotation apparently induces especially strong dynamo activity, X-ray emission, and high magnetic field strengths.

From X-ray observations of λ And, we assumed that the corona was similar to that of the Sun and used coronal loop models to predict a magnetic field strength of about 1,000 Gauss covering most of the star's surface (compared to the Sun's field strength of about 10 Gauss and Earth's 0.5 Gauss). The actual measurements found almost exactly the predicted value — 1,100 Gauss covering 75 percent of the star's surface.

This one case is very encouraging, and undoubtedly there will be many more such tests in the near future. Right now, it looks as if we're on the verge of a new understanding of coronal formation and heating, and of the process of magnetic field generation in stars. The potential additional applications of this knowledge are far-reaching, encompassing essentially all areas in which hot plasma interacts with magnetic fields. This could include plasma containment in fusion research or the heating of intergalactic material in clusters of galaxies. But of course, the unforeseen applications make up the most exciting aspects of scientific research.

Leon Golub is an astrophysicist at Harvard-Smithsonian Center of Astrophysics in Cambridge, Massachusetts. His last ASTRONOMY article was "What Heats the Solar Corona?" in the September 1982 issue.

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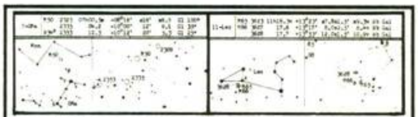

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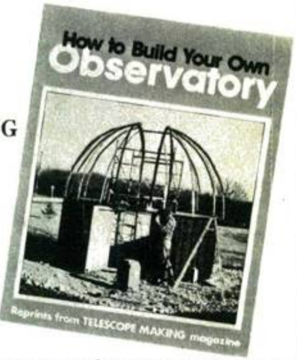
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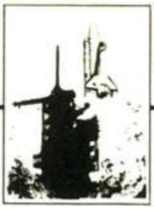

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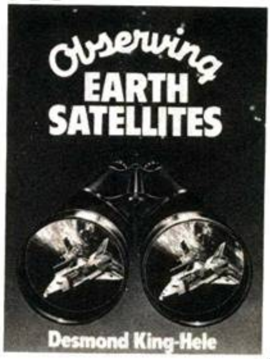

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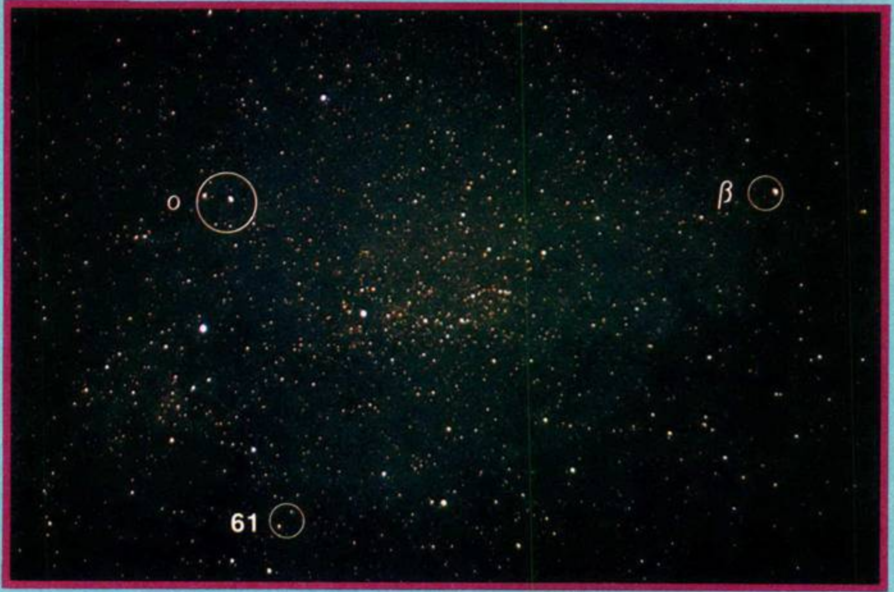


The rich starfields of Cygnus are home to many pairs, including the binocular objects 61 Cygni, Omicron (ο) Cygni, and famous Beta (β) Cygni, also known as Albireo. Photo by Mike Flick.

For a few weeks last summer, I couldn't use the observing site where I normally set up my 8-inch reflector. What to do? I certainly wasn't going to give up observing for the duration.

As an apartment dweller, I had only one option. I popped the screen out of the bedroom window and brought my trusty old 10x50 binoculars into play. The window was actually rather handy for binocular work because I could rest my elbows on the sill to steady the view.

Thanks to this circumstance, I made an interesting discovery. As I swept the starfields of western Aquila — looking for the Mira-type variable R Aquilae — a fourth-magnitude star caught my attention. When I looked carefully, I found that it was a beautiful double composed of very close, equal blue-white stars.

A quick check in *Norton's Star Atlas* revealed that the star was Theta (θ) Serpentis, a pair composed of magnitude 4.0 and 4.2 stars separated by 22.3″ of arc. I've never considered myself a double star enthusiast, but this "discovery" intrigued me. I began checking stars in the field of view for duplicity every time I observed, and found many more binocular pairs.

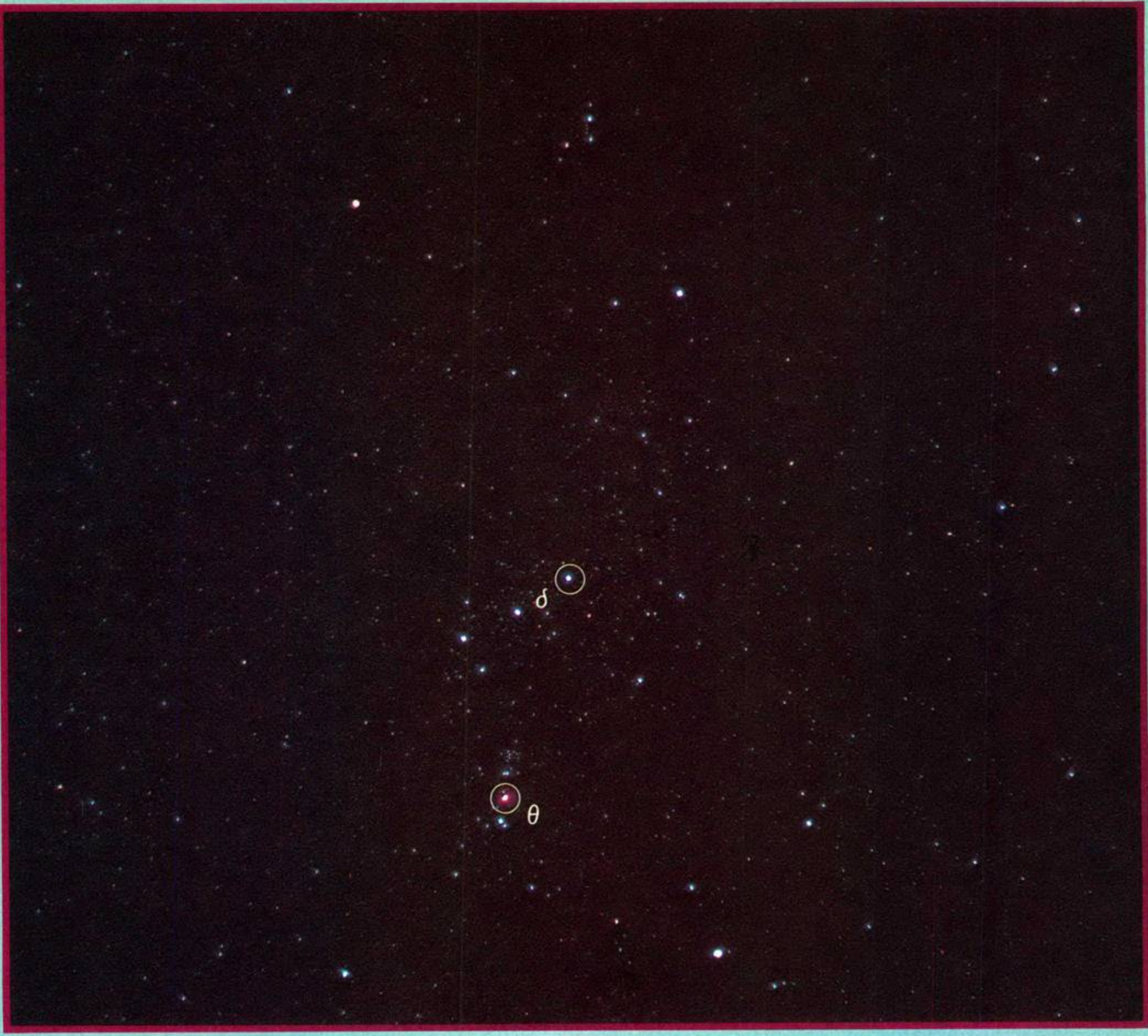
One night I followed Uranus' motion near the head of Scorpius and stumbled upon Nu (ν) Scorpii, a nice unequal pair (4.2 and 6.5, 41.4″). While monitoring an eclipsing varible star near the head of Draco, I chanced on two wide but attractive pairs, Nu (ν) Draconis (4.6 and 4.6, 61.9″) and 16 and 17 Draconis (5.0 and 5.0, 90.3″). Scanning near Vega, I found that Zeta (ζ) Lyrae (4.2 and 5.5, 43.7″) is a binocular double very similar to Nu Sco. After making these casual finds, I culled double star lists for more binocular pairs and observed a couple of dozen brighter than sixth magnitude. (There are many more seventh and eighth-magnitude doubles, as any sweep along the Milky Way confirms.)

My first objective was to determine how close a pair I could split with the 10x50s. As it turned out, I can definitely separate 100 Herculis (5.9 and 5.9, 14.2″). The two stars are distinct, although their images begin to blend together (what double star observers call a "notched" pair).

Gamma (γ) Delphini (4.0 and 5.0, 10.1″) appeared elongated on the first night that I examined it, and a check with a larger instrument showed that the elongation was in the right direction. On subsequent occasions, however, I failed to see the elongation with any certainty. My 10x50s are inexpensive, however; your binoculars may do better, even if they are nominally less powerful.

A key factor in this test is observing doubles whose components are closely equal in brightness. Perhaps I could have notched Gamma Delphini if the secondary wasn't a magnitude fainter than the primary. I certainly failed with the more equal but closer pair Gamma (γ) Arietis (4.2 and 4.4, 7.8″). So for me, the double star detection limit with 10x50 binoculars — braced against some solid support — is about 12″ separation. This is an idealized value, of course, and applies only to equal pairs that aren't too bright or too faint. Around fifth magnitude seems to be optimal — faint enough to avoid glare, yet bright enough to see the stars clearly by direct vision.

This suggests that my unaided eyes can resolve two stars separated by just 2′ (120″). A few observers with superb visual acuity can resolve 1′ (60″) with their unaided eyes, and most observers with normal eyesight can resolve 3′ (180″). How do you compare? Observe a number of binocular doubles to determine the closest pair of equal brightness that you can detect. You'll probably need to interpolate, because a nicely graded series of equal doubles isn't available. Once you determine a value for the closest detectable separation, R (in seconds of arc), in binoculars with a magnifying power of P, then the formula $R = E/P$ will



The constellation Orion holds several binocular doubles: Delta (δ) Ori, the westernmost star in Orion's belt, is an attractive pair of magnitude 2.2 and 6.7 stars, separated by 53″. Theta (θ) Ori, embedded in the heart of the Orion Nebula, is a favorite target for many binocular owners. Photo by L.H. Price.

binocular specs

When you pick up a pair of binoculars, you'll notice that it is labeled with two numbers, A x B. A equals the binoculars' magnification, and B is the clear aperture in millimeters. Thus a pair of 7 x 50s magnifies seven times; the diameter of each lens is 50mm.

What is important in a pair of binoculars? You won't want to skimp on aperture because the more you have, the more light you collect. But there's another factor: as a general rule, as you increase aperture you decrease the field of view and the ease of use of the binoculars. Objects become harder to find; it becomes much harder to steady the binoculars. The way to get around this is to decrease magnification. The "ideal" pair of binoculars — if one exists — is one with large aperture and very low magnification.

tell you your naked-eye acuity in seconds of arc (E).

Since my value of R in 10x binoculars is 12″ (120/P), my double star resolution limit in 6x glasses should be 120/6 or 20″. I don't have a pair of 6x30 binoculars, but a few test observations with a 6x30 finder confirm this value as being realistic.

What about unequal pairs? Another product of my binocular observing program is an empirical formula to predict whether I will be able to resolve an unequal double of known separation and component magnitudes. Simply put, if I can detect the duplicity of an equal pair at 12″ separation, I have to add 8″ for each magnitude of difference between the components of an unequal pair. This is expressed as $S = R + 8M$. Knowing my constant R (120/P or 12″ with 10x binoculars), and plugging in the magnitude difference in tenths, M, I can calculate the minimum detectable separation, S.

For example, the binocular double 20 Geminorum is composed of 6.0 and 6.9 magnitude stars, separated by 20.0″. Will I be able to resolve it with my 10x50s? The formula indicates that the minimum detectable separation for a pair differing by 0.9 magnitude is $12 + 8(0.9)$ or 19.2″. When I observed the star I found that I could indeed resolve it, but only with extreme difficulty.

I failed to detect the companion of Delta (δ) Orionis (2.2 and 6.7, 52.8″) the first two nights I tried. But the formula indicates that the minimum separation I should be able to detect between stars differing by 4.5 magnitudes is 48.0″. And sure enough, on a recent dark, steady night the faint companion popped out of the primary's glare — proof that observing skill improves with practice.

Will this formula work with binoculars of other sizes? If you use 6x30s, 7x50s, 8x40s, or some other size, you can find out after determining your own value for R (the least detectable separation for equal pairs), observing a variety of unequal pairs, and plugging in the magnitude differences and separations.

Several well-known stars are among the fairly short list of bright binocular doubles. Zeta (ζ) Ursae Majoris (Mizar: 2.5 and 4, 14.4″), the first known double star, may be among them, but I can't split it with 10x50s. Beta (β) Cygni (Albireo: 3.0 and 5.3, 34.3″) is one of the most observed doubles in the sky because of the vivid gold and blue color contrast it shows. Some observers find this star difficult to resolve in 7x50s, but fairly easy in 10x50s. On the same night I resolved Delta Ori for the first time, I split Albireo with a 6x30 finder, beating the formula for a 2.3 magnitude difference and 6x glasses by 4″.

Delta (δ) Cephei, the namesake for the important class of Cepheid variable stars, would be a difficult pair in 10x50s if the companion's magnitude were really 7.5, as listed in my old edition of *Norton's*. The companion is, however, at least a magnitude brighter and ought to be detectable in good 6x glasses (4 and 6.5, 40.7″).

Discordant brightness values for Delta Cep's companion appear in various lists; accurately measured magnitudes are available for only a few pairs. Most brightness values — especially for faint companions — are merely eyeball estimates. For this reason you may find some pairs easier or more difficult to split than the published brightnesses would lead you to expect.

Since Delta Cep's primary varies from magnitude 3.6 to 4.3 in a period of 5.37 days, it is interesting to compare how easily you can detect the companion when the primary is bright and when it is faint. The difference should be significant in 6x or 7x glasses.

61 Cygni is one of the closest stars to the Sun (at a distance of 11.1 light-years), and was the first star to have its distance accurately measured by stellar parallax. It's also a binary (5.3 and 5.9, 28.4″), close in 6x30s but easy in 10x50s. The orange components are virtually identical in spectral type, but the fainter star seems much ruddier in binoculars — a phenomenon several other pairs seem to show.

Finally, the Orion Nebula is home for two binocular doubles. The fifth-magnitude stars Theta^1 (θ^1)and Theta^2 (θ^2) Orionis are separated by 135″, making them easy to split with the slightest optical aid. Theta^2 forms another closer pair (5 and 6.5, 52.5″). Theta^1 is the famous "Trapezium" at the heart of the Great Nebula. A challenging multiple star for binoculars, the 5.4 magnitude primary is accompanied by a magnitude 6.3 companion 13.3″ to the northeast and a magnitude 6.8 companion 12.9″ to the northwest. This places the 6.3 and 6.8 stars some 21.5″ apart in an east-west line. Without the brighter primary and the background nebular glow, the two companions alone would be only a moderately difficult pair in 10x50s. As it is, I can see a triangular elongation of the three stars' combined images.

naked-eye doubles

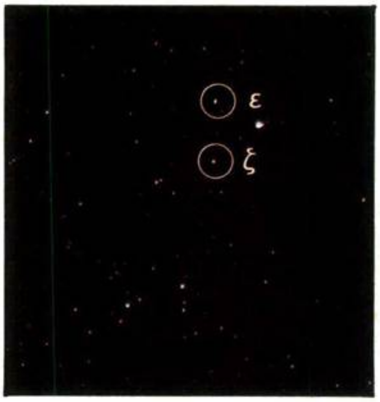
Don't own a pair of binoculars, you say? Nonsense. Just about everyone has the pair of 1x7s he was born with. The focusing mechanism and the optics may not be as sharp as when they were new, but you should still be able to split a few close doubles with them. If you can't see fourth-magnitude Alcor — Mizar's 708″ distant companion — in a dark sky, you might as well forget double star observing.

A much better naked-eye double is Alpha (α) Capricorni (3.5 and 4, 376″). I still recall the satisfaction I felt more than 20 years ago when, as a beginner, I noted that this star seemed to be double, looked it up in a star atlas, and confirmed my observation.

Theta (θ) Tauri (3.5 and 4, 337″), the star nearest Aldebaran in the "V" of Taurus, is a slightly closer pair, but for some reason I find it easier to split than Alpha Cap. I suspect that the proximity of other stars in this asterism helps the eyes to hold their focus.

A much more difficult pair is Omicron^1 (o^1) Cygni (4 and 5, 338″). The difficulty lies, of course, in the fact that the secondary is near the naked-eye magnitude limit. This pair displays a fine orange and blue contrast in binoculars, which will also reveal that the primary has a seventh-magnitude companion at 107″.

The real test of naked-eye acuity is Epsilon (ε) Lyrae (4.5 and 4.5, 208″). I've never resolved it, although I've often tried. This pair is simply too faint and too near the distracting glare of Vega for my eyes. At your next star party, see how many youngsters can beat their parents on this pair.



Epsilon (ε) and Zeta (ζ) Lyrae are two fine wide pairs in the tiny grouping of stars called Lyra. Epsilon Lyr is an excellent test of naked-eye acuity — can you split it? Photo by Steven Walther.

One word of caution: the magnitude 6.8 companion is an eclipsing variable that fades by a full magnitude for a few hours every several weeks. If you fail to resolve this star on your first try, check again on another night.

The fourth member of the Trapezium is an eighth-magnitude star 8.7″ northeast of the magnitude 6.8 member. This faint companion is just visible in a 50mm refractor at 24x, so keen eyes may be able to resolve it in good 20x50 binoculars.

Magnification — not aperture — is, in fact, the key to resolving double stars with binoculars. You may have noticed that neither the formula for equal binocular pairs nor the one for unequal pairs contains a factor for aperture. To test the true resolving power of any objective, you'll need magnification of 40x or 50x per inch of aperture. But low-power binocular eyepieces cannot be changed, so only a fraction of their objectives' full resolving power comes into play.

Thus, 7x35 binoculars will resolve a particular double just as well as 7x50s, as long as the secondary component is well above the faint magnitude limit for 35mm aperture. A pair of 16x50s will split much closer doubles than 7x50s, even though the objectives are the same aperture. With binoculars of similar magnification the paramount considerations are optical quality, the steadiness with which they are held or mounted, and the observer's visual acuity.

It's worth noting, by the way, that most of these pairs are true binaries, not just stars that happen to appear close to each other. With few exceptions, they are pairs with a common proper motion, gravitationally linked and moving through space together. If you want to observe binocular double stars, first check the list of 50 top-notch pairs on page 51 of the August ASTRONOMY. It will give you a good feel for small-aperture pairs — enough to get you off to a good start.

David Williams has been an amateur astronomer since 1957, when at the age of 12 he began observing with — what else? — binoculars. He is a former council member of the AAVSO and for several years edited the late lamented Review of Popular Astronomy.

the backyard astronomer

lacerta

Mercury

September will witness Mercury's passage out of the evening sky, through *inferior* conjunction on the 15th, and into the morning sky, where it will put on its best appearance of the year between late September and mid-October. Greatest elongation occurs simultaneously with highest elevation (9°, 45 minutes before sunrise) on October 1, but the planet will be at least 5° high beginning September 25th. The planet's azimuth will remain close to due east during the entire apparition.

Venus

Venus shifted from the evening sky into the morning sky on August 25th, when it passed between the Earth and Sun. Its subsequent morning apparition will last until early March of next year, but peak elevation comes early in November. Its climb up into the eastern sky this month will be remarkably swift. During this time Venus' phase will also change quickly; it will be interesting to monitor the changes day by day with a telescope and a medium-power eyepiece.

Earth

The Sun crosses the celestial equator from north to south at 14:42 UT on September 23rd. This marks the start of the Northern Hemisphere's autumn and the Southern Hemisphere's spring.

Mars

Mars' motion is taking it eastward toward Regulus in Leo; it will pass less than a degree north of the star on the 28th. Forty-five minutes before sunrise on that day, the pair will be about 25° high in the east. Since Mars lies almost 2.5 astronomical units away, its apparent size is very small — less than 4'' of arc. Only the distant worlds Uranus, Neptune, and Pluto appear smaller.

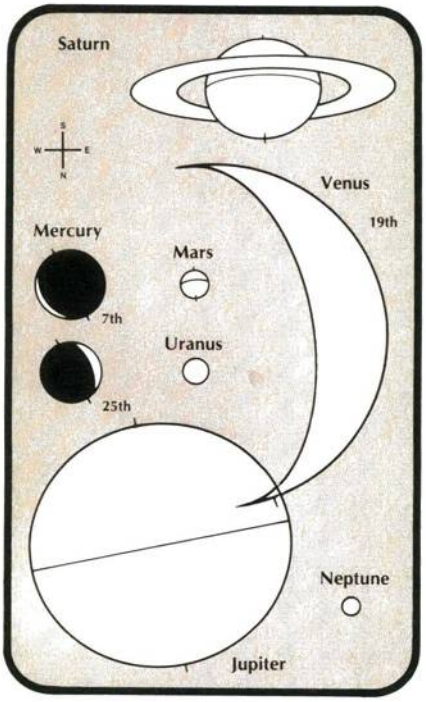
Back in March, Jack Marling traveled to Mauna Kea in Hawaii to use the Air Force 24-inch f/15 planetary patrol telescope. Using an f/7.5 focal reducer and 100 ASA film, he exposed for 15 minutes to obtain this magnificent image of Omega Centauri. Photo © 1983 University of Hawaii Institute of Astronomy.

Asteroids

1 Ceres (magnitude 7.5) lies to the south of the ecliptic on the border of Piscis Austrinus and Microscopium. Its positions:

10th: 21h 32m 06s, −29° 14.0′
20th: 21h 26m 40s, −29° 16.3′

Ceres transits around 11 p.m. local daylight time on the 15th.



2 Pallas (9.9) lies well off the ecliptic and is moving southeastward in northern Ophiuchus. Its positions:

10th: 18h 23m 28s, +11° 58.0′
20th: 18h 26m 39s, +10° 02.3′

Pallas transits about 8 p.m. local daylight time at mid-month.

3 Juno (8.4) lies in northeastern Cetus, about 7° north of Mira. Its positions:

10th: 2h 24m 43s, +5° 14.3′
20th: 2h 27m 26s, +3° 33.0′

Juno rises around 10 p.m. local daylight time on the 15th.

4 Vesta (8.1) is moving eastward in eastern Taurus, about 5° below the ecliptic. Its positions:

10th: 5h 29m 14s, +18° 00.5′
20th: 5h 38m 53s, +18° 02.8′

Vesta rises about 12:30 a.m. local daylight time in the middle of the month.

51 Nemausa (10.6) will occult the 5.8 magnitude star 14 Piscium between 7:40 and 8:00 UT on September 11th. The asteroid has a diameter of 156 kilometers and will trace a "path of totality" across the southeastern and middle Atlantic states. The predicted path is shown in the map on page 81, along with a finder chart for the star. Because the exact location of the ground track isn't known, observers who live some distance to either side of it should plan to watch.

Since 14 Piscium is relatively bright and the magnitude drop so large, any optical aid, from binoculars on up, will enable you to watch this stellar eclipse. The only other equipment you'll need is a stopwatch, necessary to time the star's black-out. After the event, send your report (listing duration, equipment used, and observing location) to the International Occultation Timing Association, P.O. Box 7488, Silver Spring, MD 20907. Remember that negative observations — where no occultation is seen — are important, too. Your observation will help astronomers determine the shape of the asteroid as well as detect any satellites it may have.

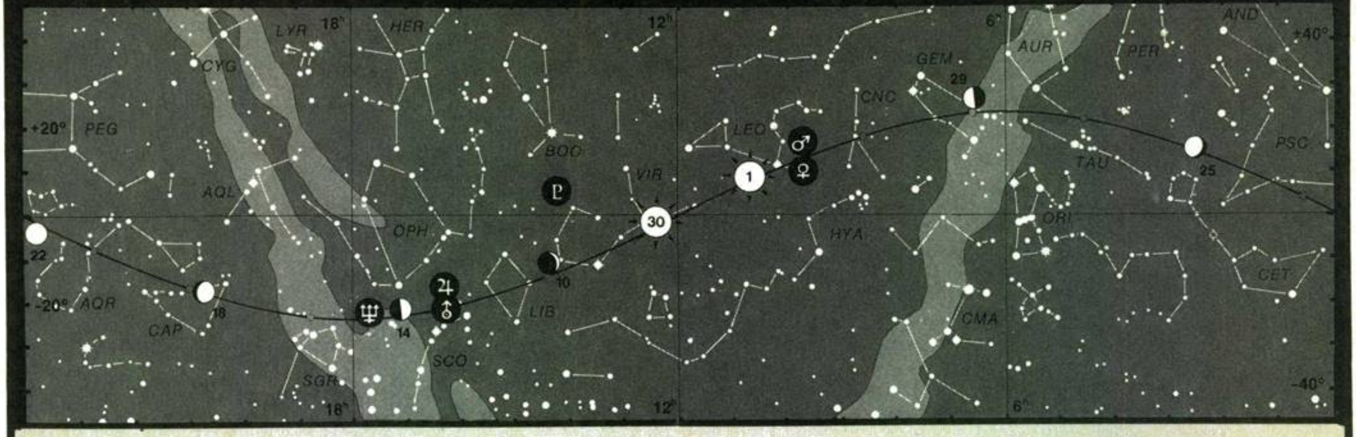
To facilitate plotting their positions on a star atlas, all asteroid coordinates are for the epoch 2000.0.

Jupiter

Jupiter has several interesting conjunctions this month. On the 3rd at 21:34 UT, it will pass 26′ south of Beta

For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

planetary data september 1983


LYR
18h
HER
12h
6h
AUR
AND
+40°
CYG
GEM
PER
CNC
29
+20°
PEG
LEO
♂
PSC
BOO
1
♀
TAU
25
AQL
♇
VIR
30
ORI
OPH
HYA
22
10
CET
♃
-20°
AQR
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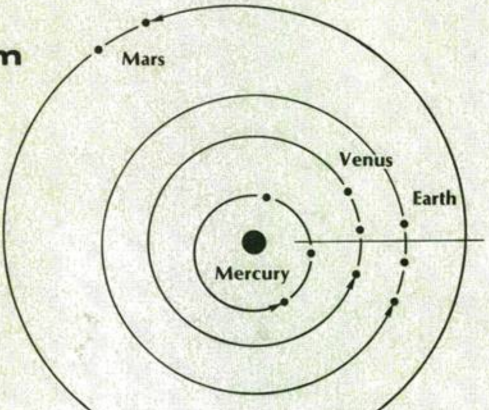
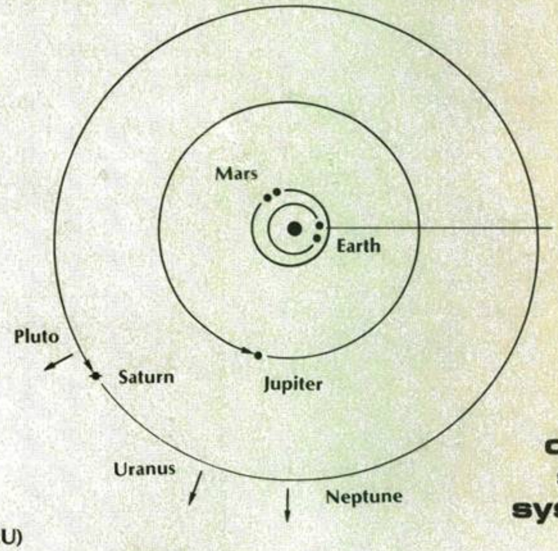
LIB
CAP
18
14
CMA
SCO
SGR
18h
12h
6h
-40°

inner solar system


Mars
Venus
Earth
Mercury


Mars
Earth
Pluto
Saturn
Jupiter
Uranus
Neptune

outer solar system

		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (1983.8)	Dec.
Sun		1	−26.7	31.7′	—	1.01	—	—	158°00.5′	10h 38.6m	+ 8°34.3′
		15	−26.7	31.9′	—	1.01	—	—	171°36.1′	11h 29.1m	+ 3°20.1′
		30	−26.7	32.0′	—	1.00	—	—	186°16.3′	12h 23.0m	− 2°29.2′
Mercury	☿	1	−1.0	9.1″	30%	0.74	0.44	297°39.2′	179°55.9′	11h 56.2m	− 3°51.6′
		15	+2.9	10.4″	1%	0.64	0.37	349°18.0′	172°28.4′	11h 28.5m	− 0°21.1′
		30	−0.1	7.3″	44%	0.92	0.31	71°42.6′	168°27.7′	11h 19.3m	+ 5°24.4′
Venus	♀	10	−4.0	52.5″	9%	0.32	0.73	356°31.3′	143°47.1′	9h 34.6m	+ 6°22.6′
		30	−4.3	39.1″	26%	0.43	0.72	28°23.6′	146°38.5′	9h 50.3m	+ 8°33.9′
Mars	♂	15	+2.0	3.9″	97%	2.42	1.64	122°11.1′	140°08.9′	9h 33.1m	+15°45.5′
Jupiter	♃	15	−1.6	35.6″	99%	5.53	5.32	254°44.7′	243°53.5′	16h 09.9m	−20°28.8′
Saturn	♄	15	+0.9	15.8″	100%	10.55	9.81	215°46.9′	211°30.3′	14h 02.3m	−10°02.1′
Uranus	♅	15	+6.0	3.6″	100%	19.22	18.97	248°25.6′	245°08.5′	16h 14.4m	−21°09.0′
Neptune	♆	15	+7.7	2.4″	100%	30.16	30.67	268°22.8′	266°04.8′	17h 44.8m	−22°10.7′
Pluto	♇	15	+13.9	0.1″	100%	30.63	29.86	209°20.9′	207°35.0′	14h 07.4m	+ 4°40.1′

moon data

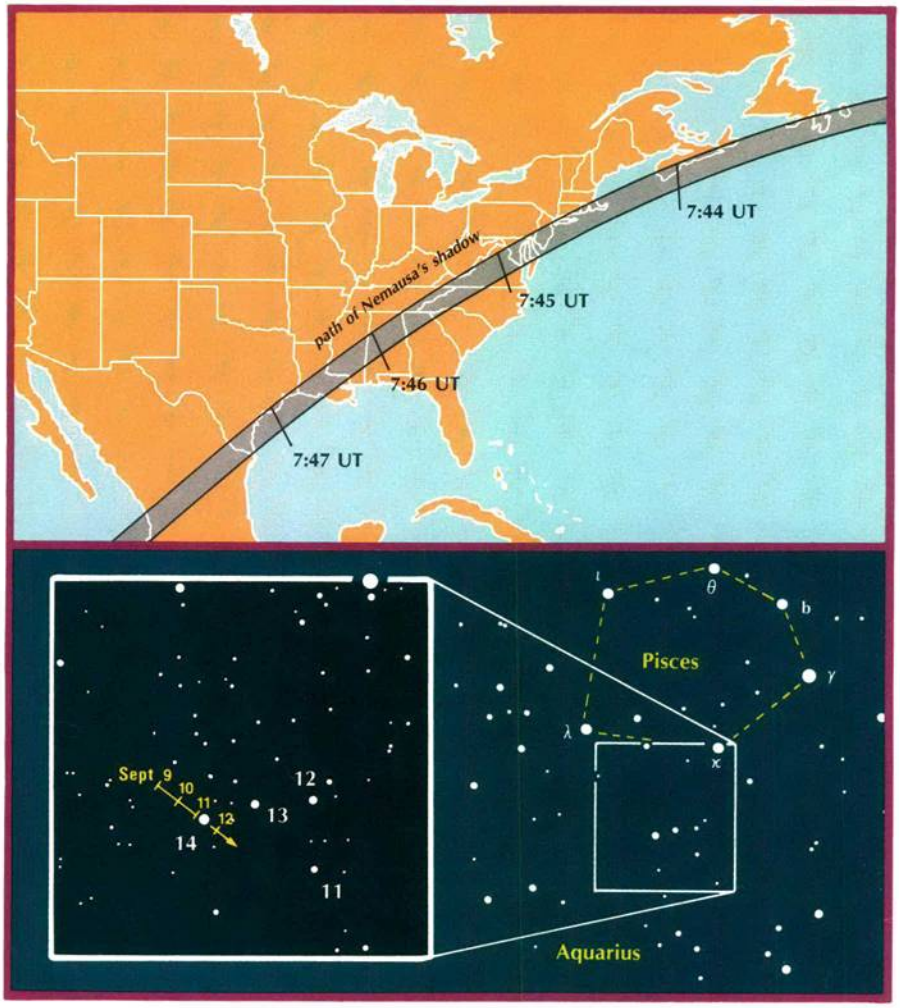
New Moon	September 7 at 2:35
First Quarter	September 14 at 2:24
Full Moon	September 22 at 6:36
Last Quarter	September 29 at 20:05
New Moon	October 6 at 11:16
First Quarter	October 13 at 19:42

Perigee: Sept. 6 at 5:10.....358,487 km.
Apogee: Sept. 18 at 16:44.....405,670 km.

universal time

Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24 hour clock. Times given in The Backyard Astronomer are UT unless noted otherwise. To convert UT into your local daylight time, subtract the following number of hours for each time zone: EDT, 4; CDT, 5: MDT, 6; PDT, 7; Alaska, 9. For example, if an event is to happen at 03:00 hours UT on June 7, then EDT for the event is 11 p.m., June 6. Likewise, 03:00 UT on September 2 becomes, in PDT, 8 p.m., September 1.

The occultation of 5.8 magnitude 14 Piscium by Nemausa on September 11 promises to be interesting. The map at right shows the path the asteroid's shadow is predicted to take; any observer living near the path should plan to watch. Below is a finder chart for the star; maps after David W. Dunham.



(β) Scorpii's brighter component. This separation is fairly wide, so use a low-power eyepiece — or even binoculars. Beta is a pretty double star whose components are of 2.6 and 4.9 magnitude.

In the evening on the 12th, the Moon (four days past New) will occult Jupiter, but the occultation isn't visible from the Western Hemisphere except in its extreme northeastern part. Observers across North America will see a close conjunction, with the Moon to the north of Jupiter.

Finally, at 21:31 UT on the 24th, Jupiter will pass 27′ north of the planet Uranus. At the time, Jupiter's disk will be 35″ in equatorial diameter and at −1.4 magnitude. Uranus' disk will be 3.5″ across and at 6.0 magnitude. As with the Beta Sco event, use low powers for the best views.

Saturn

Sinking into the evening twilight, Saturn will soon be too close to the Sun to be seen. Even as September opens, you have to observe the planet — about 15° above the horizon — through a thick blanket of air. By the end of the month, Saturn will be so low that telescopic viewing is effectively precluded. Conjunction with the Sun is on October 31st.

Uranus

Locating Uranus is easy — center your scope on Jupiter, put in your lowest power eyepiece, and scan about half a degree south and a little to the east. See the section on Jupiter for more details.

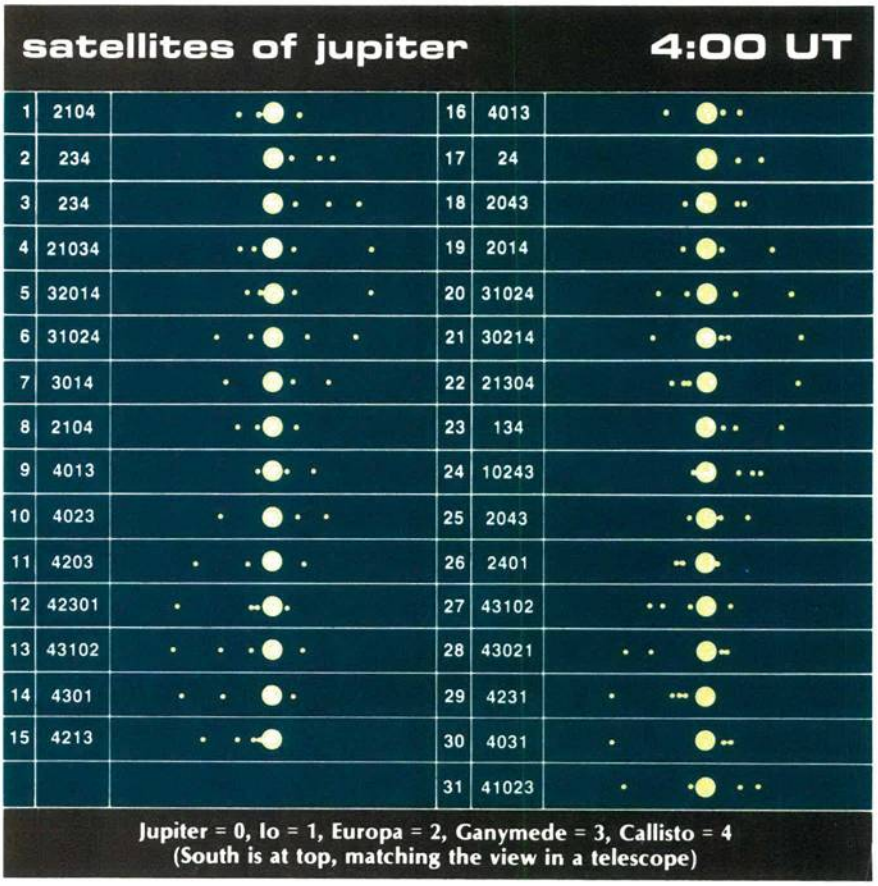
Neptune

Neptune can be found by centering your scope on the Trifid Nebula (M-20), then scanning a degree to the north and about 15m of right ascension west. Neptune has a 7.7 magnitude disk, 2.4″ across.

close-up on lacerta

Although the constellation **Lacerta** occupies a small portion of the northern summer Milky Way, it still contains numerous double and variable stars, a handful of good star clusters, one faint planetary nebula, and one of the most intriguing and mysterious of all sky objects. It is bordered by Cygnus to the west, Andromeda and Cassiopeia to the east, Pegasus to the south, and Cepheus to the north. Most of the objects in this faint outline of stars are not bright, impressive objects, but if you observe on a dark night, using care and patience, you'll enjoy them.

Probably the single most observed



satellites of jupiter **4:00 UT**

1	2104	16	4013
2	234	17	24
3	234	18	2043
4	21034	19	2014
5	32014	20	31024
6	31024	21	30214
7	3014	22	21304
8	2104	23	134
9	4013	24	10243
10	4023	25	2043
11	4203	26	2401
12	42301	27	43102
13	43102	28	43021
14	4301	29	4231
15	4213	30	4031
		31	41023

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope)

Left: Ronald Royer used an 18-inch f/7 scope and 400 ASA film to record Comet Sugano-Saigusa-Fujikawa (1983e) in this 10-minute shot made on May 11th. Right: Dick Houskeeper's shot of Sagittarius is this month's "Best Astrophoto" winner; he used a 50mm f/2.8 lens, 400 ASA film, and a 20-minute exposure.

deep-sky object in Lacerta is open cluster **NGC-7243**, a seventh-magnitude group of 40 stars in an area spanning 21′ of arc. Use a low-power eyepiece on this group — the Milky Way starfields in Lacerta are moderately rich, so you'll want to look at clusters using a wide field. NGC-7243 is elongated, arranged roughly in a "C" shape, and curls northward, opening at the top. A 3-inch scope shows an ill-defined haze, a 6-inch shows the shape of the group, and a 10-incher reveals over 40 stars in and around the moderately bright arc. How many stars can you count in this arc? NGC-7243 contains the triple star Σ2890, which is composed of a pair of magnitude 8.5 stars separated by 9.4″ (position angle 11°) and a magnitude 9.5 star 73″ away (p.a. 278°).

Another bright open cluster in Lacerta is **NGC-7209**, an 8th magnitude group of 50 stars of 9th through 12th magnitude. This group is just as large as NGC-7243 and only a bit fainter. Again, use low powers to observe this object, at least at the start. You can switch to higher powers to inspect small areas of these clusters, but the best overall view comes with about 5x to 8x per inch of telescopic aperture. A misty, grainy patch of stars in 3-inch scopes, 7209 shows many right-angled patterns of tiny stars in a 6-inch instrument. A 10-incher shows 75 stars in a 15′ diameter and many more out to the 25′ diameter — but not all of these are true cluster members.

NGC-7245 is a fainter, smaller open cluster than the previous two. It is composed of 50 dim stars — 13th magnitude and fainter — whose combined glow equals magnitude 11.5. The cluster is spread over a 6.5′ diameter, so it is a fairly rich grouping of suns, although it isn't compressed much toward the center. Because the stars are so faint, anything less than large amateur telescopes shows this object as a mottled cluster with a faint haze over its surface. On the northern side of NGC-7245 is the faint cluster **King 9**. This object is a real challenge for deep-sky observers: it shines at 14th magnitude, measures 2.5′ across, and is composed of 18th magnitude stars. You'll probably need a 16-inch telescope to detect its presence; it is invisible in 10-inch scopes even under good conditions.

Although the star clusters in Lacerta aren't as impressive as those on the Messier list, the constellation does contain top-notch double and variable stars. **AR Lacertae** is an eclipsing variable — a pair of supergiant stars that undergo an eclipse similar to Algol's once every two days. The two stars are of G5 and K0 spectral types; their combined motion causes the system to oscillate between magnitude 6.8 and 7.6. Look at this object and some comparison stars for a period of about a week. You'll see it gain and lose an entire magnitude as it "blinks off" every couple of days. Another variable in Lacerta is **S Lacertae**, a long-period variable that brightens to magnitude 7.8 and dips to magnitude 13.0 over 240-day intervals. (S Lac is predicted to reach minimum on October 31.) This makes for an interesting small telescope project: monitor S Lac's brightness every couple of weeks, making sketches of its brightness compared to nearby stars of similar magnitude. If you use, say, a 3-inch telescope, you'll easily see S Lac when it's near maximum. But over weeks of periodic checking, the star will vanish completely as it approaches 13th magnitude. How many consecutive weeks can you see this star in your small scope?

CP Lacertae is also known as Nova Lacertae 1936. On June 20, 1936, this star reached magnitude 2.2 after brightening from an anonymously dim 15th magnitude. In just three days, CP Lac increased its brightness by a factor of 175,000. By New Year's Day, 1937, the star had faded to 11th magnitude; it has continued to dim still further. It now shines at about magnitude 14.8 and is visible as a tiny white speck in large backyard scopes. (See the box on page 84 for a detailed map.)

One of the nicest high-magnification sights in Lacerta is the quadruple star **8 Lacertae** (also known as Σ2922). This foursome of bright stars includes a pair of sixth-magnitude white stars separated by 22″ (p.a. 186°), a magnitude 10.5 star at a distance of 48″ (p.a. 169°), and a magnitude 9.5 star 81″ away from the pair (p.a. 145°). Use a wide-field ocular on this group, and you'll be pleased with the smattering of stars mixed with the Milky Way background. A 2-inch scope at 30x splits the two main stars, and a 3-inch or 4-inch instrument at 100x easily shows all

Tim Pickering created this fine colorful shot of Cygnus and its nebulosities with his 50mm f/1.4 lens and 400 ASA emulsion. Piggybacking the unit on his Newtonian, he exposed for 12 minutes.

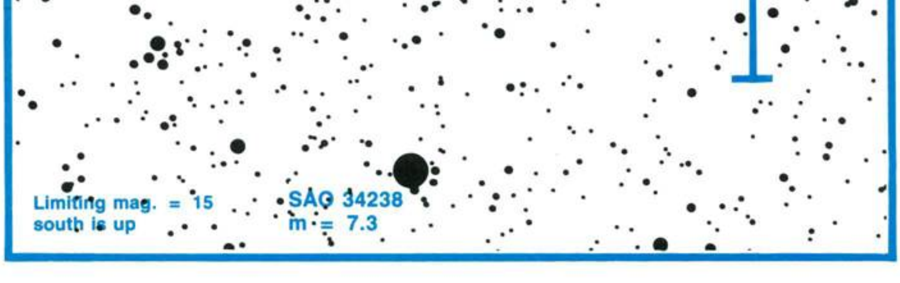
four stars. Some observers note that the 10th magnitude star appears greenish and the 9th magnitude star bluish. What colors do you see in 8 Lac?

Argelander 44 is a pair of eighth-magnitude white stars separated by a mere 7.2″ (p.a. 169°). Try high powers on this nice pair; you'll see a clean inky black gap of space between the two stars. A final double star this month is **Σ2894**, a sixth-magnitude white primary with an eighth-magnitude secondary offset 15.8″ (p.a. 194°). This pair is easy to separate, and low powers in 6-inch and 8-inch scopes show quite a pleasing view. Some observers claim they see a bluish tint in the secondary. What do you think?

The single planetary nebula in the constellation is **IC 5217**, a dim, small object that probably requires at least a 6-inch telescope to detect. The little shell of gas measures 8″ x 6″ across and glows at magnitude 12.5, so if you have a moderately large scope, you should be able to pick it up with high power. It appears fairly diffuse and unconcentrated, and displays its 14th magnitude central illuminating star in large amateur telescopes. This is a difficult object; don't be discouraged if less than perfect seeing keeps you from finding it.

Lacerta is not known for a preponderance of deep-sky objects. But it does contain **BL Lacertae**, the prototype of one of the most fascinating classes of "active" galaxies. The object was originally thought to be a variable star, hence the designation BL. But BL Lac is actually an odd cousin to the quasars: it emits huge amounts of radio energy, though unlike a quasar shows a featureless spectrum with no emission or absorption lines. BL Lacertae objects remain somewhat mysterious, especially in their relationship to quasars, Markarian galaxies, Seyfert galaxies, N-type galaxies, Zwicky galaxies, and — most important — normal galaxies. The Space Telescope should help solve these questions, leading to a more concrete understanding of how galaxies work.

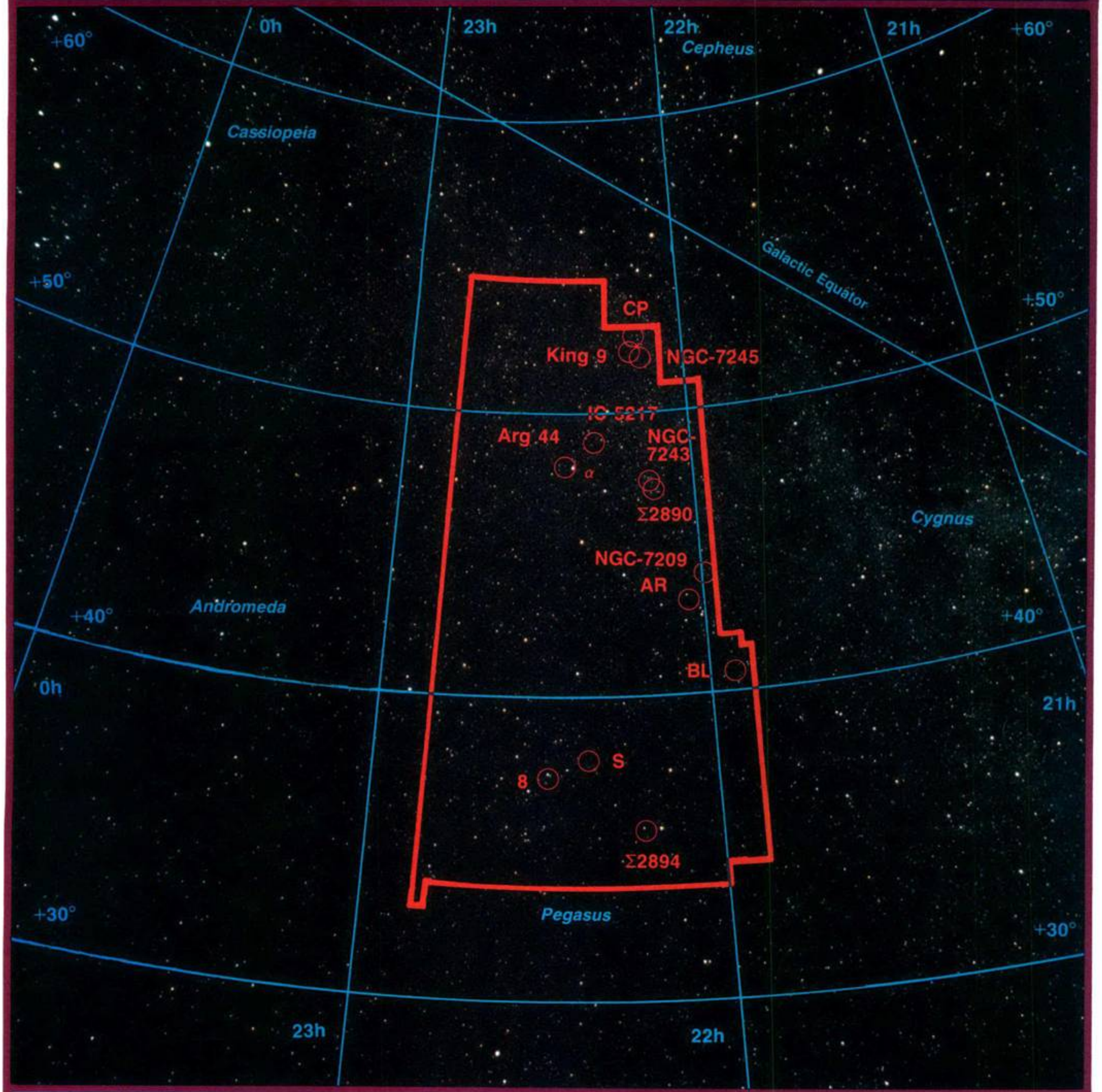
BL Lac is a tough target for backyard observers: it irregularly — and sometimes suddenly — varies in light output between magnitude 14.1 and 15.7, making it impossible to detect in any instrument of less than 12 or 14 inches in aperture. If you have a large telescope, chart its precise coordinates on a star atlas; then go out and look at the field, and see if you can identify a tiny speck in the right place. It certainly won't be easy, but remember that in deep-sky observing the most difficult observations are often the most satisfying.



Map by
David J. Eicher

lacerta

Photo by Robert Provin
and Brad Wallis


0h
23h
22h
21h
+60°
+50°
+40°
+30°
Cepheus
Cassiopeia
Galactic Equator
Cygnus
Andromeda
Pegasus
CP
King 9
NGC-7245
IC 5217
Arg 44
α
NGC-7243
Σ2890
NGC-7209
AR
BL
S
8
Σ2894

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.	R.A. (2000)	Dec.
BL	AGN	14.1↔15.7	Irr	22h 01m	+42°02′	22h 03m	+42°17′
NGC-7209	⊙	7.8	25.9′	22h 02m	+46°16′	22h 04m	+46°31′
AR	EV	6.8↔7.6	1.98d	22h 07m	+45°30′	22h 09m	+45°45′
NGC-7243	⊙	6.7	21.0′	22h 13m	+49°38′	22h 15m	+49°53′
Σ2890	★^{3}	8.5,8.5,9.5	9.4″,73″	22h 13m	+49°38′	22h 15m	+49°53′
NGC-7245	⊙	11.5	6.5′	22h 14m	+54°05′	22h 16m	+54°20′
CP	IV	2.2↔15.6	—	22h 14m	+55°22′	22h 16m	+55°37′
King 9	⊙	14.0	2.5′	22h 14m	+54°09′	22h 16m	+54°24′
Σ2894	★^{2}	6.0,8.0	15.8″	22h 17m	+37°31′	22h 19m	+37°46′
IC 5217	■	12.6	7x6″	22h 22m	+50°43′	22h 24m	+50°58′
S	LPV	7.8↔13.0	240d	22h 27m	+40°04′	22h 29m	+40°19′
Arg 44	★^{2}	8.0,8.0	7.2″	22h 32m	+50°07′	22h 34m	+50°23′
8	★^{4}	6.0,6.5, 10.5,9.5	22.3″,+ 47.8″,81.1″	22h 34m	+39°23′	22h 36m	+39°39′

★	*Star*
★^{2}	*Double Star*
★^{3}	*Triple Star*
RV	*Regular Variable*
SRV	*Semi-Regular Variable*
IV	*Irregular Variable*
EV	*Eclipsing Variable*
⊙	*Open Cluster*
●	*Globular Cluster*
■	*Planetary Nebula*
□	*Bright Diffuse Nebula*
0	*Elliptical Galaxy*
§	*Spiral Galaxy*
∮	*Barred Spiral Galaxy*
#	*Peculiar/Irregular Galaxy*

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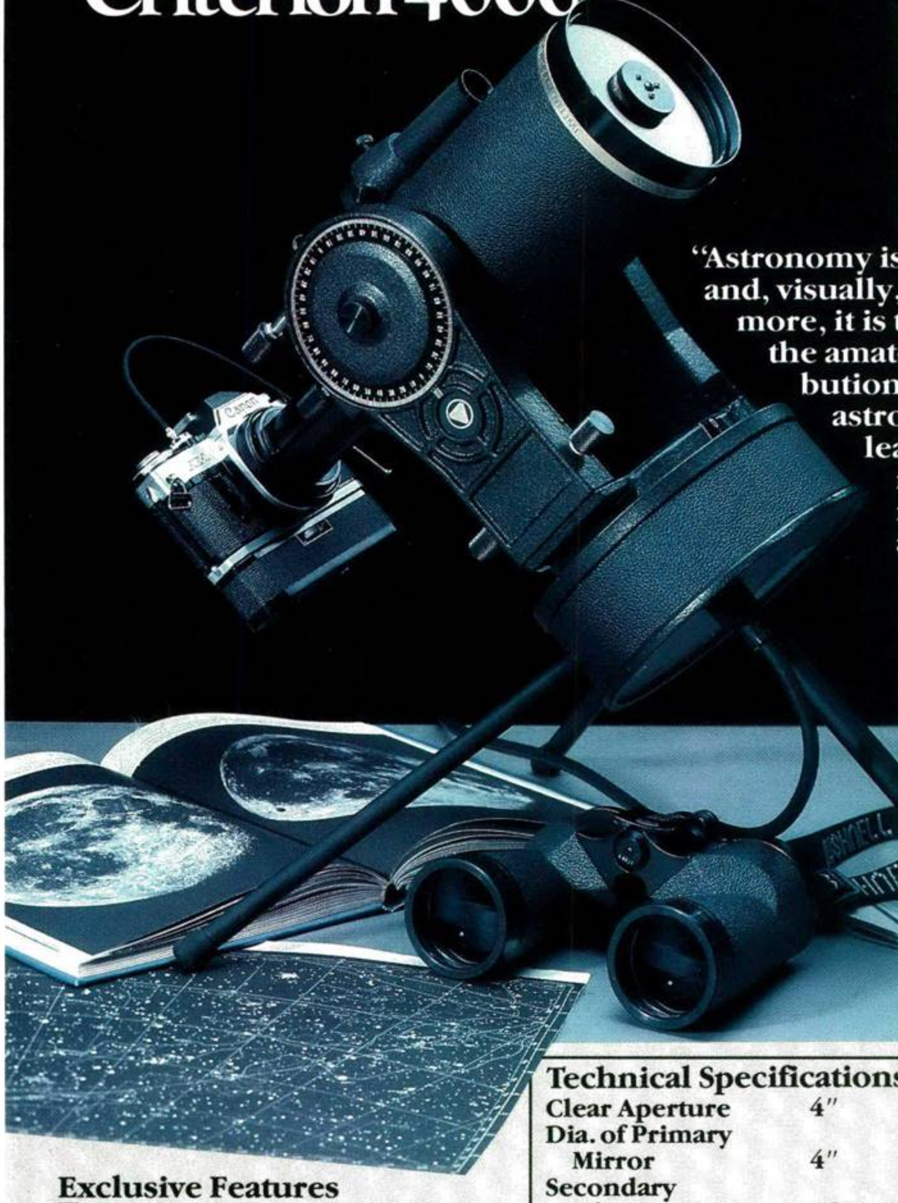

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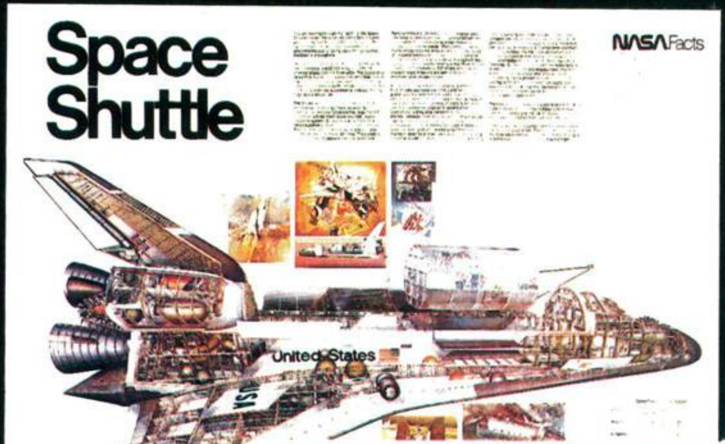

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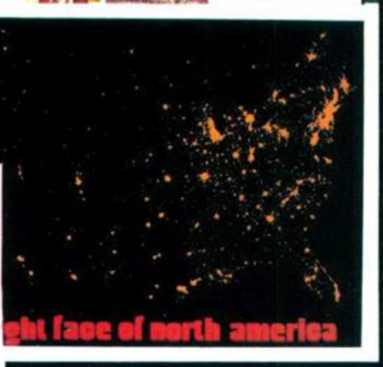

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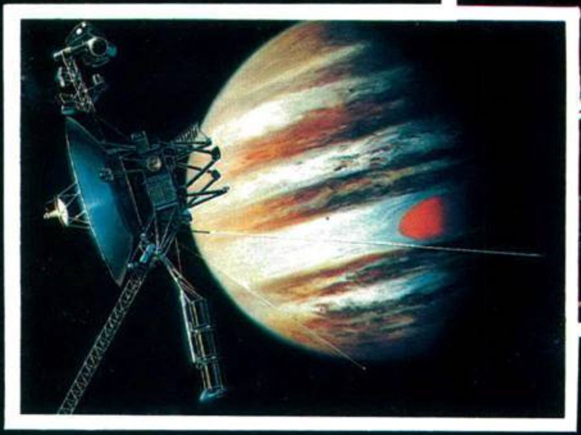

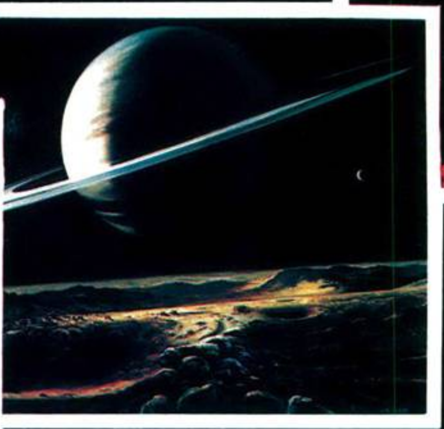

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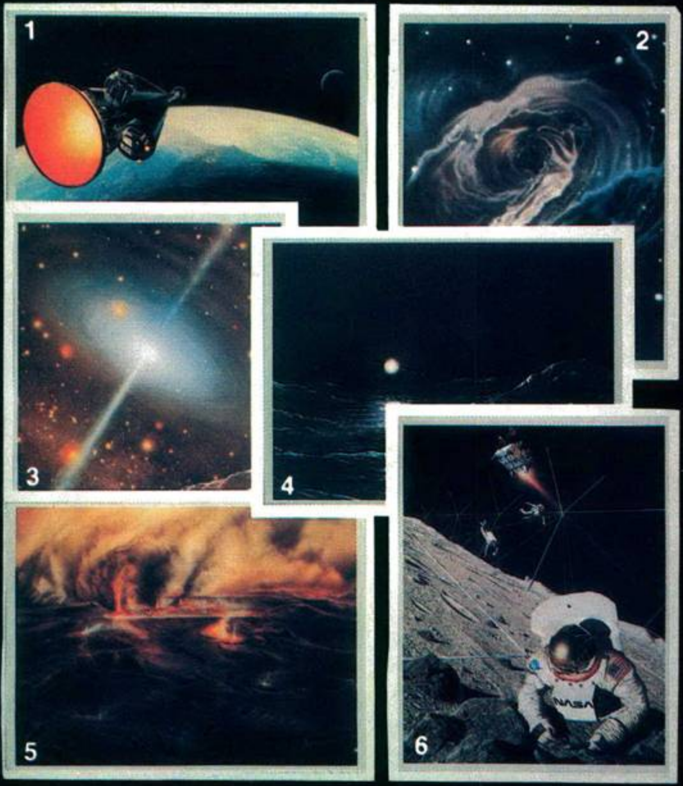

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